International Harmonized Research Activities
Pedestrian Safety Working Group

2001 REPORT

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ACKNOWLEDGEMENTS

The 2001 Report describes activities so far and fruit of efforts of the IHRA Pedestrian Safety Working Group. This report is prepared with collaboration of all the experts of this WG and the authors of each chapter are shown below.

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In addition, Mr. Hiroshi Ishimaru and Ms. Asuka Katsuragawa are in charge of secretariat and editing.
As a chairman, I would like to express my sincere appreciation to all of our experts and supporting personnel for their contribution to make this report fruitful and productive.

Yoshiyuki Mizuno
Chairman

CHAPTER 1: SUMMARY

1.1 Introduction

Back in May 1996, the 15th ESV International Conference was held at Melbourne, Australia. Anteceding this Conference, six items of International Harmonized Research Activities (IHRA) were proposed and endorsed in the ESV Government Focal Point Meeting under the initiative of the U.S. DOT/NHTSA and these items were formally presented to the 15th ESV International Conference. As a result, six projects were launched with an aim to propose harmonized test procedures reflecting the latest traffic accident condition. For each project, a leading country was designated and a working group (WG) was formed by ESV participating countries to achieve assignments within the timeframe of five years.

The primary tasks assigned to the Pedestrian Safety WG (PS-WG) were:

(a) to investigate and to analyze the latest pedestrian accident in the IHRA member countries, and

(b) to establish harmonized test procedures that would reflect such accident condition and would induce vehicle structures to be improved for the reduction of fatalities and alleviation of severe injuries in pedestrian vs. passenger car crashes.

These tasks would be carried out with the cooperation of all IHRA member countries.

1.2 Pedestrian Safety Working Group Experts

In response to the Japanese government's invitation of IHRA member countries to join the PS-WG, experts were appointed and the intention to participate in the WG was expressed by Australia, European Commission (represented by EEVC), Japan and the United States of America. In addition, experts were registered from the automobile industry (OICA), while the chairman was appointed by the Japanese government. The activities of the PS-WG were started by these experts. (See Appendix A for member list.)

1.3 Meetings

The experts were assigned various tasks relating to the two above-mentioned activities [(a)&(b)], at the 1st PS expert meeting which was held in Tokyo in July 1997. A total of nine PS expert meetings have since been held alternately in Japan, the U.S., Europe and Australia to discuss assigned tasks and to execute the projects.

1.4 Accident Study Result and Its Data

One of the assigned tasks is to investigate the recent pedestrian-car collision accidents in the IHRA member countries. Special and time-consuming investigations were required to obtain data worthy of detailed accident analysis. Such data were supplied by Australia, Europe, Japan and the U.S. and were compiled as a pedestrian accident IHRA data-set.

The injury sustaining body regions of pedestrians and the injury inflicting areas of passenger cars were first identified. Then, study priority was determined from injury severity and frequency data according to the body regions of pedestrians. The top-priority items were decided to be the development of test procedures to achieve reduction of head injuries of adults and children and test procedures to achieve reduction of lower leg injuries of adults.

The following are the specific priorities decided:

Adults 1st: Head; 2nd: Lower leg and Knee; 3rd: Chest, abdomen, pelvis/femur
Children 1st: Head; 2nd: Chest, abdomen, pelvis
In selecting the impactors for the child head tests, the finding that the frequency of child accidents peaks in six-year olds was taken into account and a headform impactor representing a six year old child was therefore chosen. The case of adult headform and legform impactors, properties representing a 50% male adult were chosen.

At the first meeting of the IHRA pedestrian safety-working group, it was agreed that development of harmonized test procedures would be based upon real world crash data. Pertinent pedestrian and vehicle information contained in accident survey databases was accumulated. Pedestrian information included age, stature, gender, injured body region, and injury severity. Vehicle information included vehicle type, make, and year, mass, pedestrian contact location, damage pattern, and impact velocity. Other general accident information such as pedestrian crossing pattern, weather conditions, vehicle and pedestrian trajectories, alcohol use, etc. were also of interest if collected. Bicycle or motor-driven cyclists were not included in the study. Four injury databases from Australia, Europe, Japan and the United States were identified as containing much of this information. Multiple injuries per case were included in the dataset. Data from these four studies were combined into a single database for further analysis to develop a better basis for worldwide pedestrian impact conditions. From each of these studies, seven fields of information were identified which were common to all four studies and would provide crucial guidance in test procedure development. These fields are country, case number, age, impact velocity, AIS level, injured body region, and source of injury as illustrated in Table 1.1.

Table 1.1 IHRA Dataset Illustration

COUNTRY	CASE_NO	AGE	AIS	Body Region	Vehicle Region	Impact Velocity
Australia	PED005-99-p1	19	2	1	5	100
Japan	9710067	43	6	13	11	50
Germany	8292	37	2	7	10	90
USA	97-90-628	18	2	11	1	58
Germany	9654	54	4	1	2	65
Japan	9810079	23	6	1	4	95

Chapter 3 details the inter-relationships between these seven fields, and conclusions are drawn about the current state of pedestrian crashes by analyzing the combined dataset. This analysis includes:

- Pedestrian injuries by body part and vehicle contact source
- Pedestrian crashes by age, region/country, and impact velocity
- Injury AIS levels by age and impact velocity
- Impact velocities of pedestrian crashes by age group
- Impact velocities by AIS level injury for head and leg injuries

1.5 Biomechanics & Computer Simulation

An adult pedestrian is run under by a passenger car. The head and lower limbs are the most frequently and severely injured body regions, and most of the severe injuries are due to the impact with the vehicle, not with the road. Hence the design of the vehicle is a major determinant of pedestrian injury and its protective properties are best determined by subsystem tests which simulate impacts between the vehicle and the head and leg of the pedestrian. The tolerance of the head to impact is measured using the Head Injury Criterion.
Similar criteria for the tolerance of the leg and knee joint to lateral impact from the bumper and leading edge of the bonnet are currently being considered.

Mathematical models are being used to study the kinematics of the pedestrian/vehicle collision. Models of both the adult and the child pedestrian are applied to three categories of frontal shapes of passenger vehicles.
Computer simulation was performed by NHTSA (-U.S.A.-), JARI (-Japan-) and the Adelaide University (-Australia-), who utilized their own pedestrian-car collision models and adopted vehicle shape and car crash speeds of 30, 40 and 50 km/h as common parameters. On the basis of their simulation data, analysis was performed on the ratio impactor speed/car crash speed, head impact angle and head effective mass, among other factors.
The results are then used as a guide to the conditions for the headform subsystem test. Further work is still required to resolve differences between the output of the three models and to validate them against data from actual pedestrian/vehicle collisions.

1.6 Study of Passenger Car Front Shape

With the collaboration of OICA, information on the front shapes of passenger cars currently on sale in IHRA member countries was collected and analyzed. As a result, cars were divided into three categories: sedan, SUV and one-box. A corridor specifying the uppermost and lowermost dimensions of the vehicle front shape was produced for each of the three car categories. The corridors were utilized to analyze, by computer simulation, the effects of the above-mentioned dimensions on test conditions such as the head impact speed, angle and effective mass of the head relative to car crash speed.

1.7 Existing Test Methods & Tools

(1) EEVC/WGs 10 & 17 Activities

Between 1987 and 1999 Working Groups 10 and 17 of the European Enhanced Vehicle-safety Committee developed pedestrian protection test methods based on a subsystem (i.e. impactor) approach. The EEVC test methods include in order of priority

1. Child headform to bonnet top tests
2. Adult headform to bonnet top tests
3. Legform to bumper tests
4. Upper legform to bonnet leading edge tests

The methods fully describe the procedures for testing, the tools (including certification) and (proposed) test requirements or criteria.

(2) ISO/TC22/SC10/WG2 Activities

More or less in the same period in time, the International Organization for Standardization created a pedestrian protection working group . This WG2 has been focussing on the adult legform test and the child/adult headform tests. The proposed test methods were based mainly, with some changes, on existing subsystem test methods.

(3) Pedestrian Dummy

A pedestrian dummy, called Polar has been recently developed in a joint collaboration of GESAC, Honda R&D, and JARI. The latest version of the dummy is known as Polar II and includes a human-like representation of the knee, a flexible tibia, and a more compliant shoulder.

1.8 Test Methods

The development of pedestrian harmonised test procedures is based on real world accident data. These data, gathered in the different countries involved in this working group, indicate that for pedestrians priority should be given to the protection of the head for both adults and children.
Initially, test procedures using a pedestrian dummy were considered, but some significant disadvantages of using pedestrian dummies for regulatory purposes became apparent. So IHRA decided to adopt the sub-system test methods and to establish specifications. Two head-forms are proposed for use in sub-system testing, one to represent an adult pedestrian head and one to represent a child pedestrian head.
Mathematical simulations of adult head impact against different categories of shapes of cars were performed, focused on head effective mass, head impact speed and angle at impact, and also wrap around distance at the head contact point; the same has to be done for the child head.
At this time, the current results are used in a draft test method for the adult pedestrian, no values are currently available for the child head test method.

1.9 Implications for Regulations – Societal and Economical

Estimates were made of the benefits in terms of casualty reductions from vehicles that will be made to meet the pedestrian impact test requirements under development by this Working Group. The Working Group is producing test methods and test tools suitable for the whole of the vehicle front likely to strike a pedestrian, so protection was therefore assumed for all impact locations in frontal impacts. As protection requirements for the vehicle and potential savings of pedestrian injuries are very dependent on the impact velocity selected for the test methods, benefits for three possible test speeds (30, 40 and 50 km/h) were estimated. For each speed, two methods were used to calculate the proportions injured at speeds at which the test procedures could provide protection: a) A simplified assumption that those saved above the test speed will match those not saved below. b) An assumption that the safety measures will shift the injury severity distribution upward in speed. The estimates are shown in Table 1.2.

Table 1.2 Potential reductions in pedestrian fatal and serious casualties due to cars passing IHRA test methods, as a percentage of pedestrians injured by all vehicle types

Test Speed (km/h)	'Safe within test speed' method		'Speed-shift' method	
	Fatal (%)	Serious (%)	Fatal (%)	Serious (%)
30	5	17	13	7
40	14	27	35	19
50	26	33	48	29

1.10 Achievements

This project has run for 4 years since July 1997, and 9 expert meetings have been held.
Over this period, detailed information on pedestrian-involved traffic accidents in member countries has been gathered and analyzed to propose appropriate harmonized test procedures as a basis for future harmonization of the regulations.
After careful consideration, it was decided to use subsystem test procedures which are more practical and repeatable than full scale tests.
Proposals for head impact subsystem test procedures for adult and children, which are top-priority issues, are nearly complete. Proposals for the adult leg test procedures are being considered. Other areas of the human body will be researched in the future.
In the field of pedestrian crash injury biomechanics, there is a need for further investigation for practical applications.
We plan to first clarify the issues, necessities and research responsibilities through detail investigations. The following issues will be studied:
(1) Comparative evaluation of the result of subsystem test procedures and computer simulation based test procedures.
(2) Regarding leg impact, we will reconfirm injury mechanisms, tolerance, available impactors, and develop test procedures reflecting the results of these studies.
(3) Clarification of the importance of injury mechanisms to the areas other than head, leg, and research into and the development of impactors to confirm such injury mechanisms.

1.11 Future Work

IHRA/PS-WG submitted its work plan (new terms of reference) to the IHRA Steering Committee in May 2001, and it was approved without any change.
Based on this work plan, the WG will try hard to finalize the test procedures on adult/child head protection by the middle of 2003 and also the test procedures on adult leg protection by the middle of 2005.
Concerning other body region's test procedures, the WG members need further review and discussion. Once its specific idea (proposal) is decided, the WG is to propose its additional action plan to the Steering Committee After the Committee's approval, the WG will make necessary action to finalize the approved tasks.

CHAPTER 2: INTRODUCTION

2.1 IHRA Activities

Back in May 1996, the 15th ESV International Conference was held at Melbourne, Australia. Anteceding this Conference, six items of International Harmonized Research Activities (IHRA) were proposed and endorsed in the ESV Government Focal Point Meeting under the initiative of the U.S. DOT/NHTSA and these items were formally presented to the 15th ESV International Conference. As a result, six projects were launched with an aim to propose harmonized test procedures reflecting the latest traffic accident condition. For each project, a leading country was designated and a working group (WG) was formed by ESV participating countries to achieve assignments within the timeframe of five years.

2.2 Objective of Pedestrian Safety

The primary tasks assigned to the Pedestrian Safety WG (PS-WG) were:

(a) to investigate and to analyze the latest pedestrian accidents' data in the IHRA member countries, and

(b) to establish harmonized test procedures that would reflect such accident condition and would induce vehicle structures to be improved for the reduction of fatalities and alleviation of severe injuries in pedestrian vs. passenger car crashes.

These tasks would be carried out with the cooperation of all IHRA member countries.

2.3 Approach of Application Systems

Bio-mechanics in the aspect of pedestrian accident and development of test devices based on such bio-mechanics are still in the process of research. Because a pedestrian dummy had not been developed at the beginning of this project and it would need enormous time and/or fund for its development, the PS-WG had to give up the idea of using a pedestrian dummy after consulting to the IHRA/Bio-WG. Beside this situation, the WG experts believe component test method have several merits such as repeatability, simplicity, impact locations of the vehicle can freely chosen, cost of the test, etc. Therefore, the PS-WG carefully considered and decided to make use of the existing "component (sub-systems) method" employed by the ISO (TC22/SC10/WG2) and EEVC/WG17, while ready to research into areas not covered by available knowledge. As one of the two primary tasks assigned to the PS-WG, detailed research was conducted into the accident condition in Australia, Europe, Japan and the U.S. The collected accident data were analyzed to determine the impact areas of vehicles, accident frequency and injured regions of pedestrian vs. passenger car crashes and to decide research priorities from these findings. According to the priorities thus decided, the PS-WG embarked on its research activities.

CHAPTER 3: ACCIDENT DATA

At the first meeting of the IHRA pedestrian safety-working group, it was agreed that development of harmonized test procedures would be based upon real world crash data. Pertinent pedestrian and vehicle information contained in accident survey databases was accumulated. Pedestrian information included age, stature, gender, injured body region, and injury severity. Vehicle information included vehicle type, make, and year, mass, pedestrian contact location, damage pattern, and impact velocity. Other general accident information such as pedestrian crossing pattern, weather conditions, vehicle and pedestrian trajectories, alcohol use, etc. were also of interest if collected. Bicycle or motor-driven cyclists were not included in the study. Four injury databases from Australia, Germany, Japan, and United States were identified as containing much of this information. Multiple injuries per case were included in the dataset.

In Japan, pedestrian accident data collected by JARI between 1987 and 1988 and in-depth case study data of pedestrian accidents conducted by ITARDA between 1994 and 1998 were combined for inclusion into the IHRA accident dataset. A total of 240 cases were acquired in the cities surrounding the Japan Automobile Research Institute (JARI).

In Germany, investigation teams from both the Automotive Industry Research Association and Federal Road Research Institute collected accident information in a jointly conducted project called the German In-Depth Accident Study (GIDAS). A total of 783 cases collected between 1985 and 1998 were included from the cities of Dresden and Hanover and their surrounding rural areas. Accident investigation took place daily during four six-hour shifts in two-week cycles. The respective police, rescue services, and fire department reported all accidents continuously to the research teams. The teams then selected accidents according to a strict selection process to avoid any bias in the database. Accidents where a passenger car collided with more than one pedestrian or one pedestrian collides with more than one passenger car were not considered. Furthermore, accidents in which the car ran over the pedestrian or the impact speed could not be established were not considered. the study included information such as environmental conditions, accident details, technical vehicle data, impact contact points, and information related to the people involved, such as weight, height, etc.

Detailed information from pedestrian crashes was collected in the United States through the Pedestrian Crash Data Study (PCDS)[i,ii]. In this non-stratified study, a total of 521 cases were collected between 1994 and 1999. Cases were collected from six urban sites during weekdays. If, within 24 hours following the accident, the pedestrian could not be located and interviewed or the vehicle damage patterns documented, the case was eliminated from the study. In order for a case to qualify for the study, the vehicle had to be moving forward at the time of impact; the vehicle had to be a late model passenger car, light truck, or van; the pedestrian could not be sitting or lying down; the striking portion of the vehicle had to be equipped with original and previously undamaged equipment; pedestrian impacts had to be the vehicle's only impact; and the first point of contact between the vehicle and the pedestrian had to be forward of the top of the A-pillar.

The Australian data is from at-the-scene investigations in 1999 and 2000 of pedestrian collisions in the Adelaide metropolitan area, which has a general speed limit of 60 km/hr. Ambulance radio communications were monitored from 9 am to 5 pm, Monday to Friday, and from 6 pm to midnight on two nights per week. Ambulance attendance at a pedestrian accident was the only criterion for entry into the study. The sample consists of 80 pedestrian/vehicle collisions, including 64 with passenger cars, SUV and 1-box type vehicles, where the pedestrian was standing, walking, or running, and where the main point of contact with the pedestrian on the vehicle was forward of the top of the A-pillar. Pedestrians and drivers were interviewed, wherever practicable, as part of the investigation process. The reconstruction of the impact speed of the vehicle was based on physical evidence collected at the scene. Injury information was obtained from hospital and coronial records, the South Australian Trauma Registry and, in minor injury cases, from an interview with the pedestrian.

Data from these four studies were combined into a single database for further analysis to develop a better basis for worldwide pedestrian impact conditions. From each of these studies, seven fields of information were identified which were common to all four studies and were crucial to providing guidance in test procedure development. For each injury, these seven fields of data were collected and input into the unified pedestrian accident database. The seven fields were country, case number, pedestrian age, impact speed, AIS injury level, body region injured, and vehicle source causing the injury (Table 3.1). Injury body region and vehicle source were categorized as shown in Table 3.2.

Table 3.1 IHRA Dataset Illustration

COUNTRY	CASE_NO	AGE	AIS	Body Region	Vehicle Region	Impact Velocity
Australia	PED005-99-p1	19	2	1	5	100
Japan	9710067	43	6	13	11	50
Germany	8292	37	2	7	10	90
USA	97-90-628	18	2	11	1	58
Germany	9654	54	4	1	2	65
Japan	9810079	23	6	1	4	95

Table 3.2 Injury Body Regions and Sources

Injury Body Regions
Head
Face
Neck
Chest
Abdomen
Pelvis
Arms
Leg Overall (Specific part not identified)
Femur
Knee
Lower Leg
Foot
Unknown Injury

Injury Sources
Front Bumper
Top Surface of Bonnet/Wing
Leading Edge of Bonnet/Wing
Windscreen Glass
Windscreen Frame/A-Pillars
Front Panel
Other Vehicle Source
Indirect Contact Injury (Non-Vehicle)
Road Surface
Unknown Source

The number of cases and total injuries represented in this combined database are shown in Table 3.3. Throughout the remainder of this report, this dataset is denoted as the IHRA Pedestrian Accident Dataset. It is recognized that pedestrian injuries in developing countries are not represented in this dataset; however, this data is the most comprehensive pedestrian accident database available to guide pedestrian safety test procedure development. A total of 3,305 injuries of AIS 2-6 severity were observed, and there were 6,158 AIS=1 injuries observed (Table 3.3). These minor (AIS=1) injuries were excluded in the following analysis because they were not believed to be crucial in test procedure development.

Table 3.3 IHRA Pedestrian Accident Dataset

Region	Cases	Injuries	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6	AIS 2-6
Germany	782	4056	2616	877	405	89	56	13	1440
Japan	240	883	523	182	94	29	47	8	360
USA	518	4179	2837	599	477	144	99	23	1342
Australia	65	345	182	93	36	12	17	5	163
TOTAL	**1605**	**9463**	**6158**	**1751**	**1012**	**274**	**219**	**49**	**3305**

IHRA pedestrian injuries of AIS 2-6 severity are shown in Table 3.4 according to the part of the body that was injured. As shown in this table, head (31.4%) and legs (32.6%) each accounted for about one-third of the AIS 2-6 pedestrian injuries. Of the 3,305 AIS 2-6 injuries, 2,790 (84%) were caused by contact with portions of the striking vehicle, with head and legs being the most frequently injured (Table 3.5). Head injury accounted for 824 occurrences, and legs a total of 986 injuries when combining overall, femur, knee, lower leg, and foot body regions. Windscreen glass was the most frequent vehicle source of head injury, with the windscreen frame/A-pillars and top surface of bonnet/wing both being substantial additional sources of injury to the head. A further breakdown of the injuries and vehicle sources for children and adults is shown in Tables 3.6 and 3.7. For children, the top surface of the bonnet is the leading cause of head injury, while a substantial number of child head injuries also occur from windscreen glass contact. For adults, the windscreen glass is the leading source of head injury, followed by windscreen frame/A-pillars and top surface of the bonnet and wing. Not surprisingly, the bumper was the leading source for both child and adult pedestrian leg injury.

Table 3.4 Distributions of Pedestrian Injuries (AIS 2-6) by Body Region and Country

Body Region	USA	Germany	Japan	Australia	TOTAL
Head	32.7%	29.9%	28.9%	39.3%	31.4%
Face	3.7%	5.2%	2.2%	3.7%	4.2%
Neck	0.0%	1.7%	4.7%	3.1%	1.4%
Chest	9.4%	11.7%	8.6%	10.4%	10.3%
Abdomen	7.7%	3.4%	4.7%	4.9%	5.4%
Pelvis	5.3%	7.9%	4.4%	4.9%	6.3%
Arms	7.9%	8.2%	9.2%	8.0%	8.2%
Legs	33.3%	31.6%	37.2%	25.8%	32.6%
Unknown	0.0%	0.4%	0.0%	0.0%	0.2%
TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**

Table 3.5 IHRA Pedestrian Injuries by Body Region and Vehicle Contact Source – All Age Groups; AIS 2-6

Contact	Body Region	Head	Face	Neck	Chest	Abdomen	Pelvis	Arms	Legs					Unknown	Total
									Overall	Femur	Knee	Lower Leg	Foot		
Part of the Vehicle	Front Bumper	24	2		3	5	3	6	19	59	76	476	31	1	705
	Top surface of bonnet/wing	223	15	2	139	44	43	86	23	3	1	1	2	1	583
	Leading edge of bonnet/wing	15	2	4	43	78	85	35	50	40	6	30	1		389
	Windscreen glass	344	56	12	30	5	12	23	2			1	1	1	487
	Windscreen frame/A pillars	168	28	5	35	7	14	31	5	1				2	296
	Front Panel	5	1		9	13	7	6	9	14	11	35	3		113
	Others	45	7	1	38	12	13	15	15	9	5	39	18		217
	Sub-Total	824	111	24	297	164	177	202	123	126	99	582	56	5	2790
	Indirect Contact Injury	13		17	1	1	7	1		3		1	2		46
	Road Surface Contact	171	22	2	22	2	9	42	6	4	3	5	15	1	304
	Unknown	27	6	3	19	10	16	25	1	7	9	32	3	7	165
	Total	1035	139	46	339	177	209	270	130	140	111	620	76	13	3305

Table 3.6 IHRA Pedestrian Injuries by Body Region and Vehicle Contact Source – Ages > 15; AIS 2-6

Contact Location	Body Region	Head	Face	Neck	Chest	Abdomen	Pelvis	Arms	Legs					Unknown	Total
									Overall	Femur	Knee	Lower Leg	Foot		
Part of the Vehicle	Front Bumper	20	2		2	3	3	3	16	29	69	429	29		605
	Top surface of bonnet/wing	140	9	1	122	39	35	73	21	3	1	1	2	1	448
	Leading edge of bonnet/wing	7	2	1	36	65	80	28	46	33	5	24	1		328
	Windscreen glass	303	52	11	28	3	10	22	1			1	1		432
	Windscreen frame/A pillars	159	28	5	34	7	14	29	5	1				2	284
	Front Panel		1		8	13	6	5	9	9	10	32	3		96
	Others	33	7		29	9	12	11	6	4	5	26	13		155
	Sub-Total	662	101	18	259	139	160	171	104	79	90	513	49	3	2348
	Indirect Contact Injury	12		16	1		7			3		1	2		42
	Road Surface Contact	125	18	2	21	2	8	32	6	4	3	5	14	1	241
	Unknown	19	6	3	18	9	16	20	1	4	9	28	3	6	142
	Total	818	125	39	299	150	191	223	111	90	102	547	68	10	2773

Table 3.7 IHRA Pedestrian Injuries by Body Region and Vehicle Contact Source – Ages < 16; AIS 2-6

Contact Location	Body Region	Head	Face	Neck	Chest	Abdomen	Pelvis	Arms	Legs					Unknown	Total
									Overall	Femur	Knee	Lower Leg	Foot		
Part of the Vehicle	Front Bumper	4			1	2		3	3	30	7	47	2	1	100
	Top surface of bonnet/wing	83	6	1	17	5	8	13	2						135
	Leading edge of bonnet/wing	8		3	7	13	5	7	4	7	1	6			61
	Windscreen glass	41	4	1	2	2	2	1	1					1	55
	Windscreen frame/A pillars	9			1			2							12
	Front Panel	5			1		1	1		5	1	3			17
	Others	12		1	9	3	1	4	9	5		13	5		62
	Sub-Total	162	10	6	38	25	17	31	19	47	9	69	7	2	442
	Indirect Contact Injury	1		1		1		1							4
	Road Surface Contact	46	4		1		1	10					1		63
	Unknown	8			1	1		5		3		4		1	23
	Total	217	14	7	40	27	18	47	19	50	9	73	8	3	532

Distribution of pedestrian accident victims by age (all AIS levels) is shown in Table 3.8 and illustrated in Figure 3.1. When broken into five-year age segments, Table 3.8 indicates that the 6–10 year old age group has the highest frequency of accident involvement at nearly 14% of all cases. In Japan, this age segment accounts for 20% of the cases, while the other three regions have lower involvements in this age group. The percentage involvement in the 11-15 year old group for Japan, however, drops considerably and is lower than for Germany, the U.S., or Australia. It is unclear why this sudden drop occurs in Japan and not in the other regions. In summary, over 31% of all cases involved pedestrians age 15 and younger. This percentage is 13% higher than the average overall population of individuals in this age group in the four countries (18%), which demonstrates the magnitude of the child pedestrian problem[iii].

Table 3.8 Distribution of Pedestrian Crashes by Age and Country

Age	US	Germany	Japan	Australia	IHRA
0-5	4.6%	9.0%	9.2%	4.3%	7.3%
6-10	13.8%	14.6%	20.0%	10.6%	14.1%
11-15	13.8%	9.8%	5.0%	11.0%	9.7%
16-20	6.2%	7.3%	3.3%	7.2%	6.6%
21-25	6.2%	4.5%	1.7%	8.7%	5.5%
26-30	4.6%	4.7%	1.7%	10.1%	6.0%
31-35	4.6%	4.2%	5.4%	5.8%	4.9%
36-40	3.1%	4.5%	5.0%	7.2%	5.4%
41-45	3.1%	3.6%	3.8%	6.2%	4.4%
46-50	3.1%	4.6%	5.4%	6.2%	5.2%
51-55	3.1%	5.4%	6.7%	3.3%	4.8%
56-60	1.5%	4.5%	10.0%	3.7%	4.9%
61-65	6.2%	5.8%	6.7%	3.9%	5.3%
66-70	7.7%	3.7%	3.8%	3.3%	3.7%
71-75	4.6%	3.8%	4.2%	3.7%	3.9%
76-80	3.1%	5.0%	2.5%	3.3%	4.0%
81-85	6.2%	3.8%	3.3%	0.8%	2.9%
86-90	4.6%	1.2%	2.1%	0.4%	1.2%
91-95	0.0%	0.1%	0.0%	0.6%	0.2%
96-100	0.0%	0.0%	0.4%	0.0%	0.1%

The age distribution data contained in Figure 3.1 also provides an opportunity to demonstrate that the IHRA Pedestrian Accident Dataset is representative of the pedestrian crash situation in the United States. In addition to the Germany, Japan, U.S., and Australian pedestrian datasets, data from the FARS and GES are also included. FARS is the Fatal Analysis Reporting System, which contains every fatal traffic accident in the U.S. The GES is the General Estimates System, and is obtained from a nationally representative sampling of police-reported crashes. In general, the age distribution of the GES data is similar to the others in Figure 3.1. Since the GES is designed to be a statistically representative sample, and since the U.S. PCDS and GES distributions are similar, this would imply that the PCDS is fairly statistically representative despite the non-stratified sampling scheme used to collect PCDS cases. However, the FARS distribution differs significantly from any of the others in Figure 3.1. Because FARS contains only fatal accidents, this may be an indication that the distribution of fatal and non-fatal injuries differs from each other. An ideal comparison for the FARS data would have been with the IHRA pedestrian fatalities. But since the number of fatal cases is quite limited in the IHRA data, the FARS distribution was compared to the serious and fatal AIS≥4 injuries as shown in Figure 3.2. Although there is considerable variability remaining in this distribution due to small sample sizes, the FARS distribution has reasonable agreement with the IHRA data.

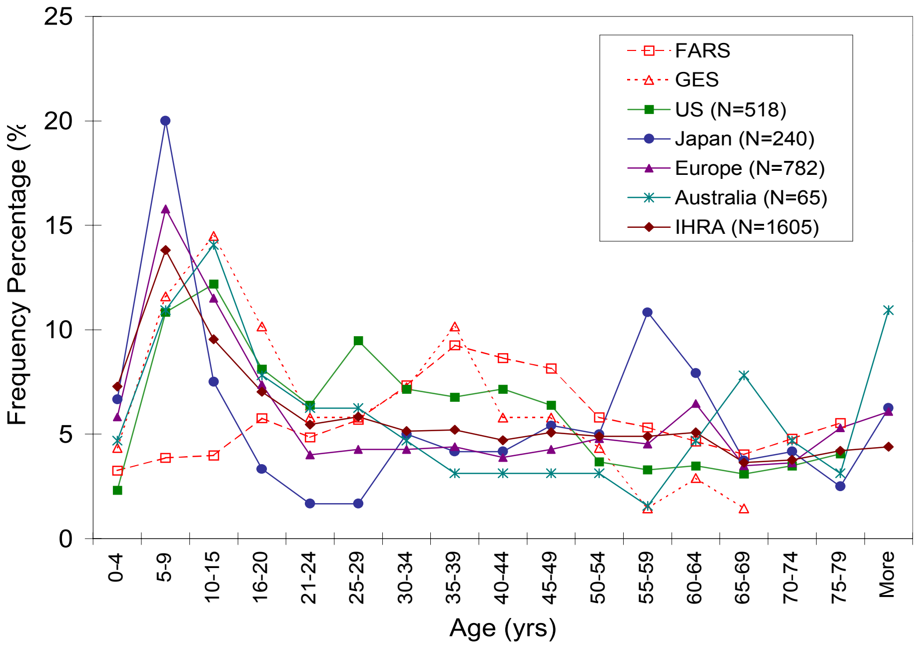

Figure 3.1 Frequency of Accidents by Age and Country

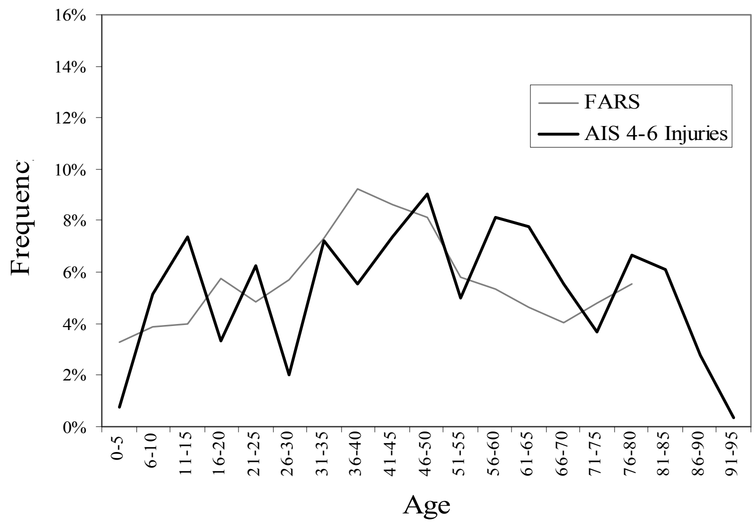

Figure 3.2 IHRA AIS 4-6 Injuries vs. FARS Data by Age

Analysis of the injury level by age group is shown in Figure 3.3. This figure shows that children aged 15 and younger tend to have a higher proportion (25%) of AIS 1 and 2 injuries than adults, and persons aged 61 and older have the highest proportion (near 30%) of moderate and serious injuries. These observations are likely the result of two factors. First of all, exposure levels may differ for the various age groups. For example, younger children tend to be involved in pedestrian collisions with lower impact velocities. As shown in Figure 3.4, the average impact velocity for children aged 0-15 is about 28 km/h. This is approximately 5 km/h lower than for the other age groups. A second cause of the injury distribution observed in Figure 3.3

may be that those aged 61 years and older are generally more frail and less resilient, leading to higher severity injury for a given impact velocity.

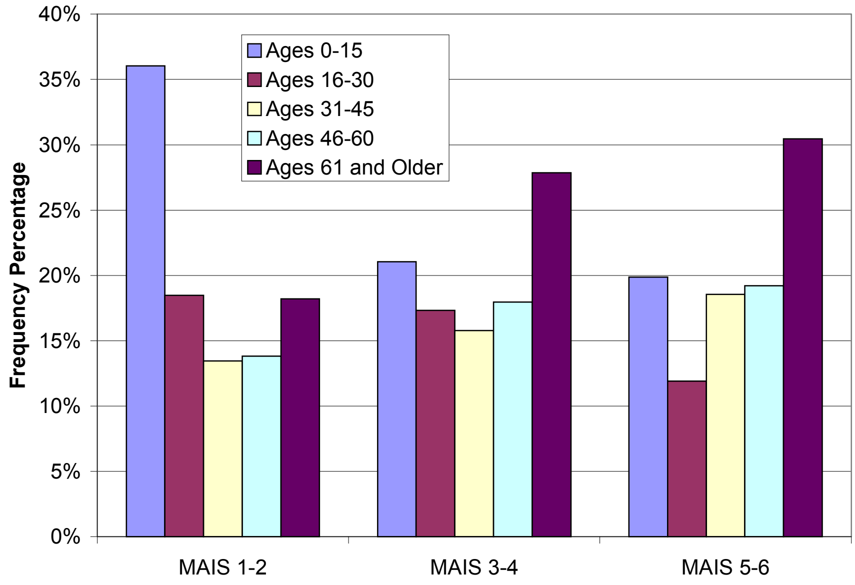

Figure 3.3 Distributions of MAIS Levels by Age

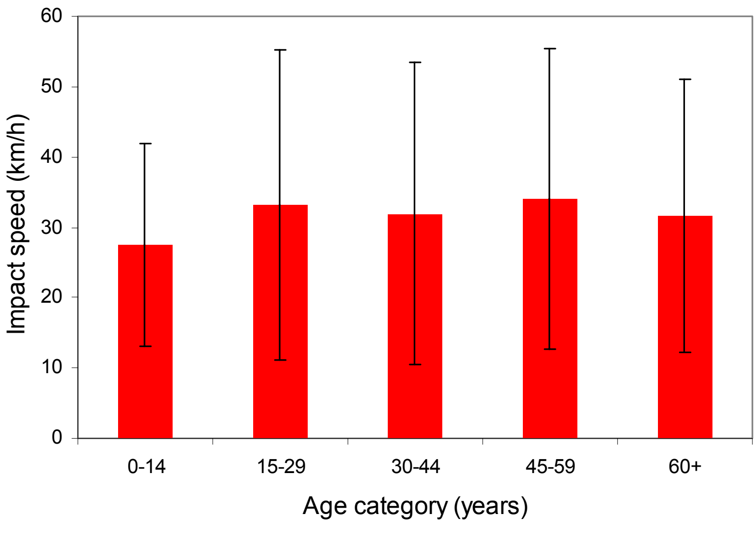

Figure 3.4 Average Impact Velocities by Age Group (MAIS 1-6)

Figures 3.5 and 3.6 provide insight into the impact velocity distribution associated with pedestrian impacts. In Figure 3.5, the cumulative frequency of impact velocities on a per case basis for each country is similar although the U.S. has a larger percentage of injuries at lower velocities than the other three countries. This is broken down further in Figure 3.6, where lower MAIS injuries occur at lower velocities for all four countries. In Figure 3.7, the MAIS injuries are broken into three categories for the four countries. For MAIS 1-2 injuries, Japan has the lowest frequency (55%) and Germany has the highest (77%). For MAIS 3-4 injuries, Australia has the lowest frequency percentage (9%) and Japan has the highest (24%). Finally, for the most severe injuries (MAIS 5-6), Germany has the lowest frequency (4%) and Japan has the highest likelihood of a life-threatening injury (20%).

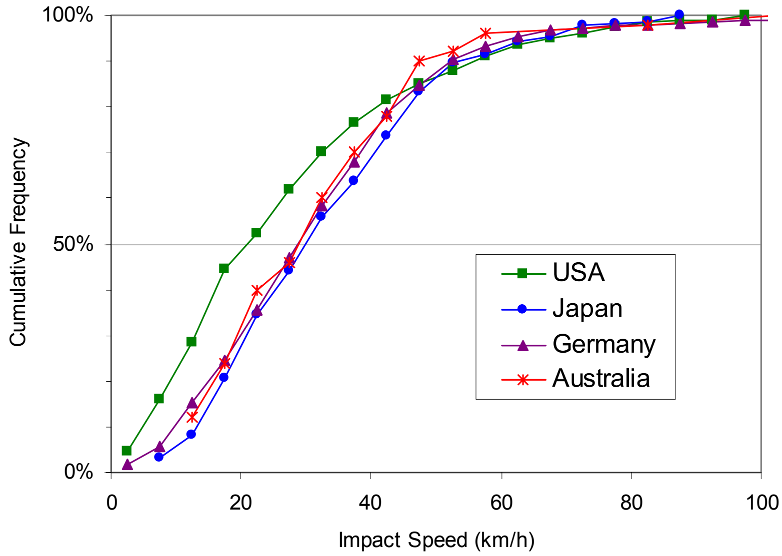

Figure 3.5 Impact Velocities by Country

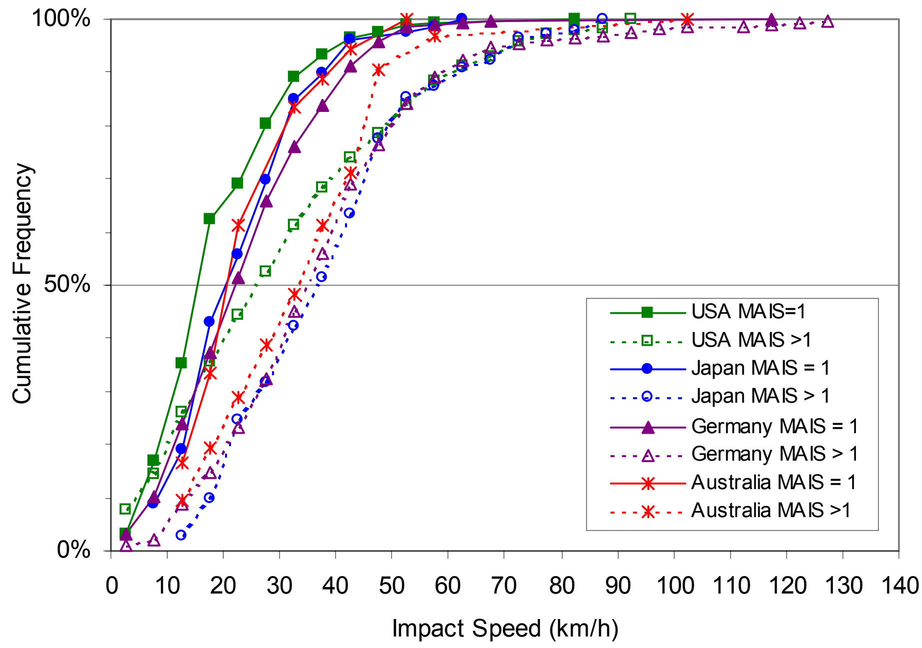

Figure 3.6 Impact Velocity by MAIS Level

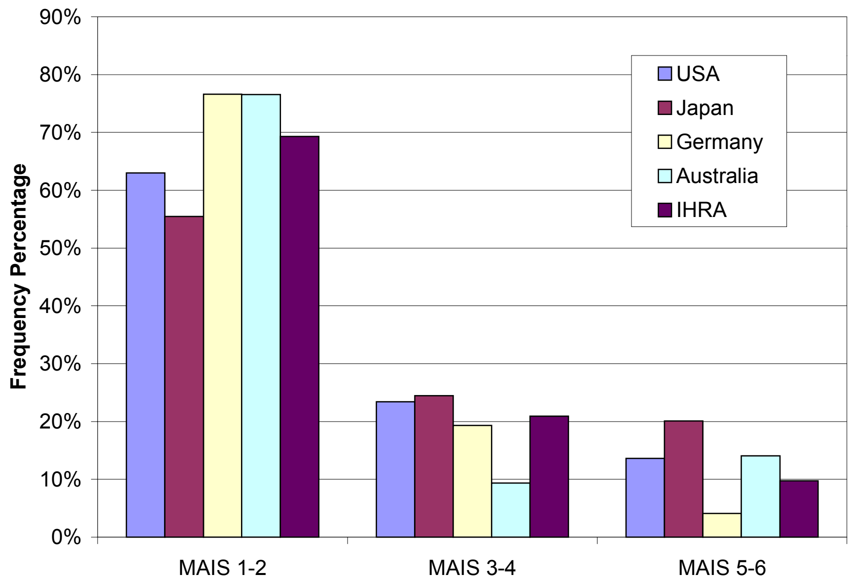

Figure 3.7 MAIS Injury by Country

The cumulative MAIS injury distributions are further broken down by age, body region, and injury severity in Figures 3.8 – 3.10. Age classifications are grouped as children (age 15 years and younger) and adults (age 16 years and older). All body regions are included for both children and adults in Figure 3.8, with distributions shown for MAIS 2-6 and MAIS 3-6 injuries. The injury distribution distinction between children and adults is evident in this figure. Children (ages 15 and under) are injured at slightly lower impact velocities than adults in most cases.

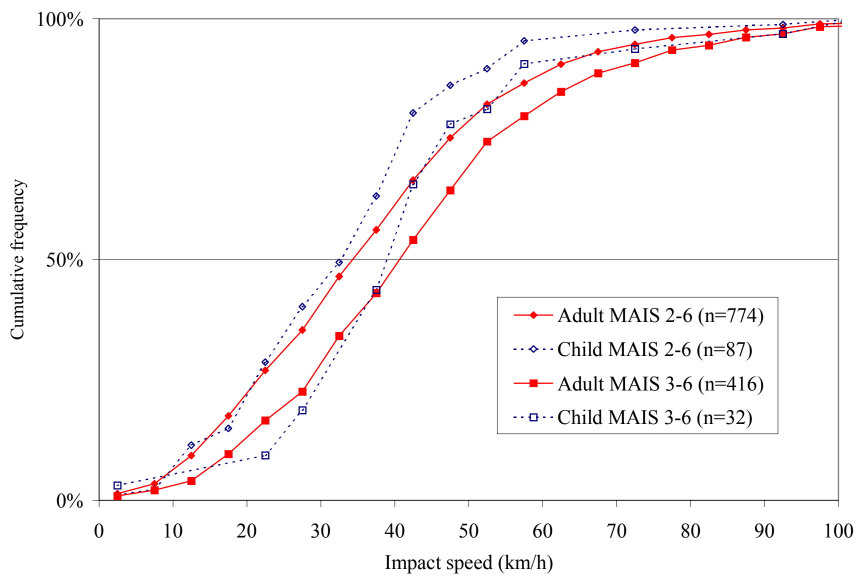

Figure 3.8 Impact Velocities by MAIS Level – All Body Regions

Head injury distributions are shown in Figure 3.9. For adults, the MAIS 3-6 and MAIS 4-6 injury distributions are almost identical, while the MAIS 2-6 distribution occurs at lower velocities. For children, there is similar separation between the MAIS 2-6, 3-6, and 4-6 injury curves, and the distributions are roughly the same shape. Once again, this figure exhibits the relationship between injury severity and impact velocity.

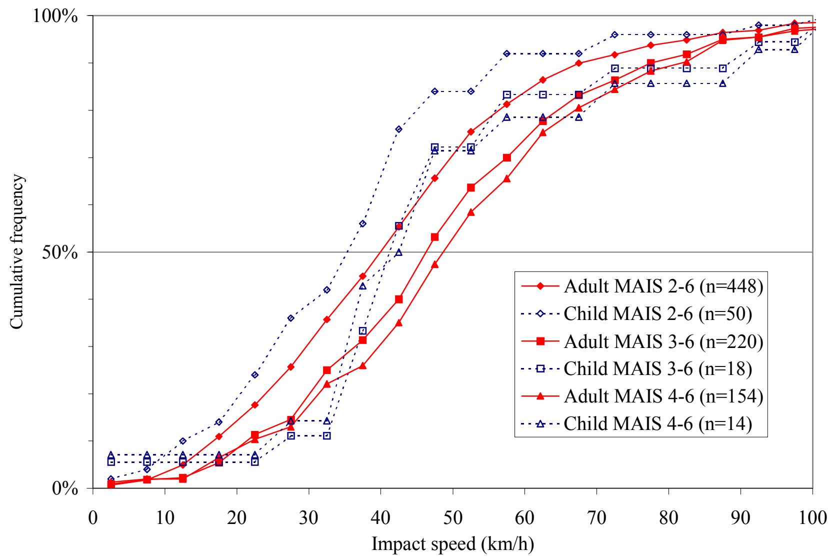

Figure 3.9 Impact Velocities by MAIS Level – Head Injuries

Injury distributions for children and adult leg injuries are shown in Figure 3.10. This figure shows that for leg injuries, injury severity is affected less by impact velocity than for head injuries. Once again, children suffer leg injuries at lower velocities than do adults.

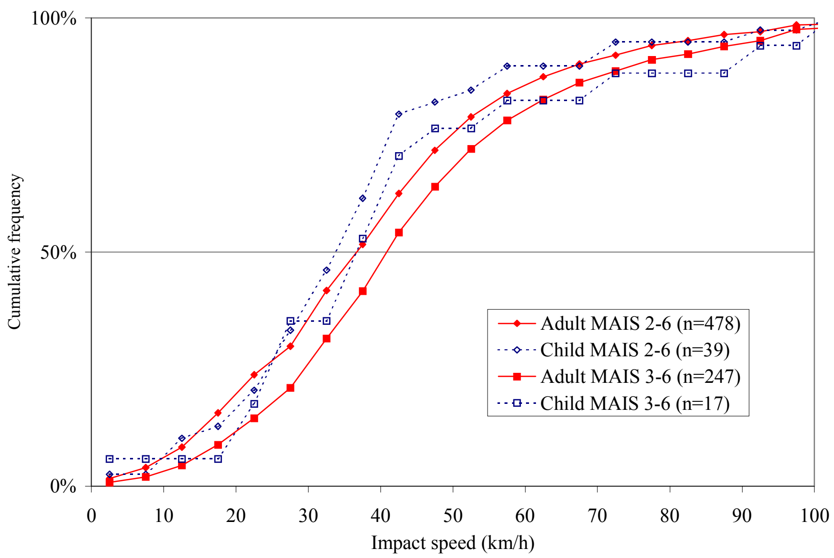

Figure 3.10 Impact Velocities by MAIS Level – Leg Injuries

The major conclusions from this analysis are:

1. The head and legs each account for almost one-third of the 9,463 injuries in the IHRA dataset.
2. For children, the top surface of the bonnet is the leading cause of head injury, while for adults the windscreen glass is the leading source of head injury.
3. Children (ages 15 and under) account for nearly one-third of all injuries in the dataset, even though they constitute only 18% of the population in the four countries.
4. Older individuals are more likely to suffer severe injuries in pedestrian crashes.
5. Children (ages 15 and under) are injured at lower impact velocities than are adults.

This compilation of pedestrian accident data from Australia, Germany, Japan, and U.S.A. provides a unique and important dataset. Issues such as the need for weighting the information included in this dataset and the problems associated with weighting are discussed in Chapter 8. In this chapter, MAIS for each case was used instead of all injuries in Figures 3.3 – 3.10 to eliminate the possibility of cases with more injuries skewing the data. The cumulative injury distribution data will provide a basis for establishing component pedestrian protection test procedures, priorities, and potential benefits assessments.

References:

[i] Isenberg, R.A., Walz, M., Chidester, C., Kaufman, R.; "Pedestrian Crash Data Study-An Interim Evaluation," Fifteenth International Technical Conference on the Enhanced Safety of Vehicles, Paper No. 96-S9-O-06, 1996.

[ii] Isenberg, R.A., Chidester, C., Mavros, S.; "Update on the Pedestrian Crash Data Study," Sixteenth International Technical Conference on the Enhanced Safety of Vehicles, Paper No. 98-S6-O-05, 1998.

[iii] United States Bureau of the Census, International Population Database (2001).

CHAPTER 4: BIOMECHANICS & COMPUTER SIMULATION

As shown in Chapter 3, in the event of an adult pedestrian being struck by a motor vehicle, the head and lower limbs are the body regions that are most likely to be severely injured. The pattern of injury differs for young children, with thoracic and abdominal injuries being relatively more common than for an adult pedestrian. This review is concentrated on injuries to the head and lower limbs, the body regions that are addressed by the subsystem tests described elsewhere in this report.

4.1 Head Injuries

The nature of the impact loading of the pedestrian's leg is unique to the pedestrian/vehicle collision. The characteristics of the impact to the head of a pedestrian also differ, to a lesser degree, from those of the impact to the head of a vehicle occupant. The objects struck are, of course, different and the distribution of impact points on the head also differs, with the pedestrian's head being more likely to be struck on the rear or the side compared with the predominantly frontal, with some lateral, impacts to the head of the vehicle occupant. (McLean et al, 1996A & B) However, for both pedestrians and car occupants, severe head injuries are most likely to be a consequence of a head impact with some part of the front of the vehicle, including the windscreen area and surrounds. A head impact with the road surface is less likely than a head impact with the car to be the cause of the most significant brain injury to a pedestrian. (Ashton et al, 1982)

4.1.1 Head injury as a cause of death

The head is the most common site of fatal injuries to a pedestrian struck by a passenger car, either alone or in combination with one or more fatal injuries to other body regions. For example, in a sample of 145 pedestrians who were fatally injured when struck by a car, 56 percent sustained a fatal brain injury. A similar percentage was observed among a sample of fatally injured car occupants but in those cases the brain injury was usually the sole cause of death whereas among the pedestrians half of those with a fatal brain injury also had at least one fatal injury to another body region. (McLean, 1995) The 44 percent of fatally injured pedestrians who did not have a fatal brain injury comprised 35 percent with a non-fatal brain injury and 9 percent with no brain injury at all. As would be expected, skull fracture was more common among those who suffered a fatal brain injury (73 percent) than among those who died from other injuries (40 percent with a skull fracture). However, it is relevant to note that this means that there was no skull fracture in about one quarter (27 percent) of those cases in which the pedestrian sustained a fatal brain injury.

There were no cases in which an injury to the brain of fatally injured road users was observed in a post mortem examination by a neuropathologist in the absence of evidence of an impact to the head. (McLean, 1995) This is relevant to an understanding of brain injury mechanisms in pedestrians struck by a conventional passenger car because the head of an adult pedestrian can be subjected to high levels of acceleration as the lower part of the body is almost instantly accelerated to the speed of the striking car and, consequently, the upper part of the body is accelerated forwards and downwards. The head is accelerated by a force acting through the neck, from almost the standing height of the pedestrian to the point at which the head impacts the bonnet, a distance of as much as one metre, in about 100 to 150 milliseconds.

4.1.2 Characteristics of the Impact to the Head of a Pedestrian

The location of a pedestrian head impact on the striking car depends largely on the size and shape of the car and the height of the pedestrian. The speed of the car on impact also influences the head impact location on the vehicle. For an adult pedestrian the head impact location on the car is therefore usually towards the rear of the bonnet or on the windscreen or an A-pillar. It may extend back as far as the top of the windshield or, in exceptional cases, the roof of the car.

In a sample of 44 cases in which a pedestrian was struck by a passenger car and there was evidence of a head impact with the car but not with the road or other object, it was found that 80 percent of the impacts were on the side or back of the head, in approximately equal frequency. (McLean et al, 1996B) In one of the 44 cases the impact was on the top of the head and in the remainder the impact was frontal. This reflects the fact that 86 percent of these pedestrians were initially struck on the side by the car. However, in about half of these cases in which the pedestrian was struck on the side, the impact was on the back of the head. The head, and probably the upper torso, had been rotated through approximately 90 degrees about the longitudinal axis of the body in the 100 to 150 milliseconds between the bumper striking the legs and the head hitting the car. This whole body rotation is thought to be a consequence of the motion of the legs on impact by the front of the car.

Despite the rotation of the upper body and head of the pedestrian prior to the head striking the car, the high proportion of impacts on the back of the head indicates that the resulting acceleration of the head is likely to be predominantly linear rather than angular. This will be less so in those cases in which the impact is on the side of the head. (Ryan et al, 1989) However, even then, impacts which may result in a high level of angular acceleration of the head can also be expected to produce a high level of linear acceleration. The evidence for the roles of linear and angular acceleration in the production of brain injury is reviewed elsewhere. (See, for example, McLean and Anderson, 1997)

4.1.3 Tolerance of the brain to impact to the head

For the purposes of this Working Group, emphasis has been placed on pedestrian head injuries resulting from head impact with the vehicle frontal structure, including the windscreen and A-pillars. The Head Injury Criterion (HIC) has been selected as the measure of the risk of brain injury resulting from these impacts. It is recognised that HIC evolved from the relationship between the duration of the impact applied to the frontal bone of the skull of a post mortem human subject, head acceleration, and the risk of the impact producing a skull fracture. It also does not allow for the influence of some factors, such as rotational acceleration of the head, or any effect of the location of the impact on the head, but it has been selected here because, at present, it is used almost universally in crash injury research and prevention. The time window for the calculation of HIC has been set at a maximum of 15 milliseconds and the value of HIC shall not exceed 1000. That HIC level is thought to correspond to a 16 percent risk of sustaining a head injury as severe as AIS 4 or greater. (Mertz et al, 1997)

4.2 Injuries to Lower Limbs

The pedestrian lower limb is typically loaded from the side (80-90 percent). Such loading conditions differ from those of lower limb of vehicle driver/occupant that are likely to be impacted in direction parallel to saggital plane. These conditions result in injuries unique to the pedestrian-car collision. Such injuries are typically a consequence of contact between the lower limb and components of a car front, such as bumper, bonnet and bonnet leading edge. They are one of the most common type of injury in non-fatal pedestrian-car collisions. For instance, in the accident data investigated by Ashton and Mackay (1979) injuries to lower limbs were sustained by 67 percent of victims with minor injuries and 72 percent of victims with non-minor, non-life threatening injuries. Similarly, more recent Japanese data (ITARDA, 1996) have indicated that lower limbs are the most commonly injured body part (40 percent) with the most severe injury.

The pattern of lower limb injuries differs between children and adults, and it has been reported in the literature that the frequency of these injuries is higher for adults than for children (Ashton, 1986). Furthermore, children are less likely to sustain pelvic and leg fractures than adults. For instance, in the UK accident data analyzed by Ashton (1986), the leg fractures have not been observed in children aged below 5 years, and the children aged 0-4 years sustained mainly femur fractures. It is clear that this injury pattern is caused by the fact that the bumper directly impacts a young child thigh.

However, it seems that insufficient experimental data are available to quantify the responses of child lower limbs in pedestrian-car collision. Therefore, the present review is concentrated on injuries to the leg and knee joint of adult pedestrian.

4.2.1 Severity of Injuries to Lower Limbs

Injuries to the lower limbs are rarely fatal. They involve fractures of fibula, tibia, and femur, as well as avulsion, rupture, and stretching of the knee joint ligaments. Such injuries are typically classified as AIS 1 to 3 (i.e., minor to serious injuries). However, they often require appreciably longer hospitalization and loss of working days than do injuries at the same AIS levels to other body regions. For instance, in the clinical study by Bunkentorp et al. (1982) healing time of tibia shaft fractures was 4-34 months, and only half of the fractures healed within 8 months. The healing time of knee and ankle injuries in their study was 2-7 months.

4.2.2 Injury Types and Injury Mechanisms to the Lower Limb of a Pedestrian

Injuries to the lower limb that have been observed in the PMHS experiments simulating pedestrian-car collisions and clinical studies are mainly fractures of tibia diaphysis (transverse and comminuted fractures of the shaft), articular fractures of tibia, cartilage damages on femoral condyles, and avulsion/stretching of the knee joint ligaments (Bunkentorp, 1982; Kajzer et al., 1997 and 1999).

The injury type depends on the following factors: 1) impact point, 2) car front part impacting the lower limb, and 3) the impact speed (*e.g.,* fracture risk is likely to increase at high impact speed). According to Bunkentorp et al. (1982), a bumper impact at or just below the knee joint is correlated with high risk of serious knee injury. Such injury may be also caused by a prominent bonnet edge. However, the bumper seems to be the main cause of injury to leg and knee joint in adult pedestrians.

4.2.3 Injury Mechanisms

According to Kajzer et al. (1997, 1999) two fundamental mechanisms of injury to the knee joint can be distinguished: 1) shearing and 2) bending. The shearing mechanism is related to translational displacement in lateral direction between the proximal leg and distal thigh at the knee joint. On the other hand, the bending injury mechanism is related to angular displacement between the leg and thigh (Fig. 4.1). Following these two injury mechanisms, two extreme loading conditions can be distinguished. The first of them corresponds to “the purest possible shearing deformation” of the knee joint (i.e., lateral impact to the leg slightly below the knee joint), whereas the second one — to “the purest possible bending deformation” of this joint (i.e., lateral impact to the distal leg end).

The typical initial injury (i.e., the injury that occurred first in a given test) associated with the shearing-type loading conditions observed by Kajzer et al. (1997, 1999) was articular fractures and anterior cruciate ligament avulsion in impacts using ram speeds of 40 km/h and 20 km/h, respectively.

The articular fractures were caused by axial compressive force between femoral and tibial condyles (Fig. 4.2). On the other hand, typical initial injury related to the bending-type loading at low impact speed (i.e., 20 km/h) reported by Kajzer et al. (1999) was avulsion/stretching of the collateral ligament on the leg side opposite to the struck area.

Furthermore, based on analysis of both the experimental data obtained using PMHS and results of mathematical modeling, it has been suggested by Yang (1997) that the risk of tibia/fibula fracture and ligament avulsion/rupture may not be independent since such fracture may protect the knee joint ligaments from injury by absorbing the impact energy.

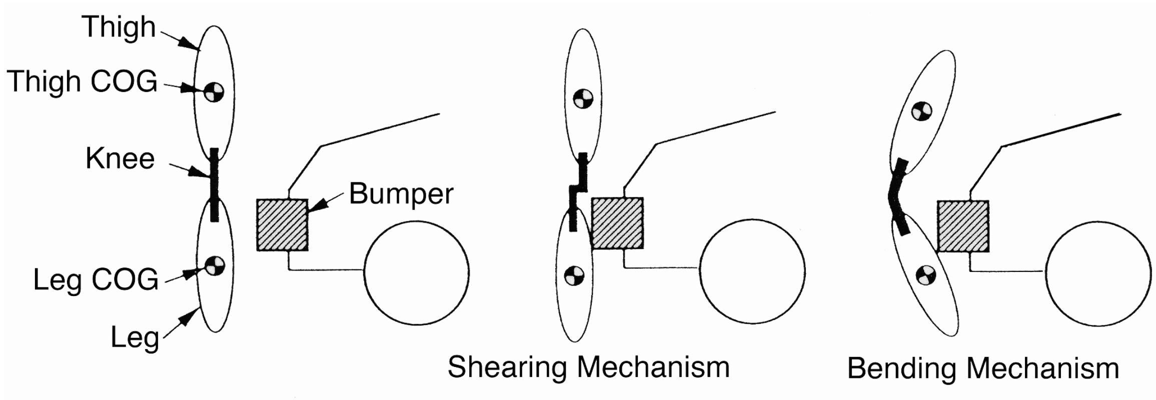

Fig. 4.1 Explanation of shearing and bending injury mechanisms of knee joint. Based on Kajzer et al. (1997).

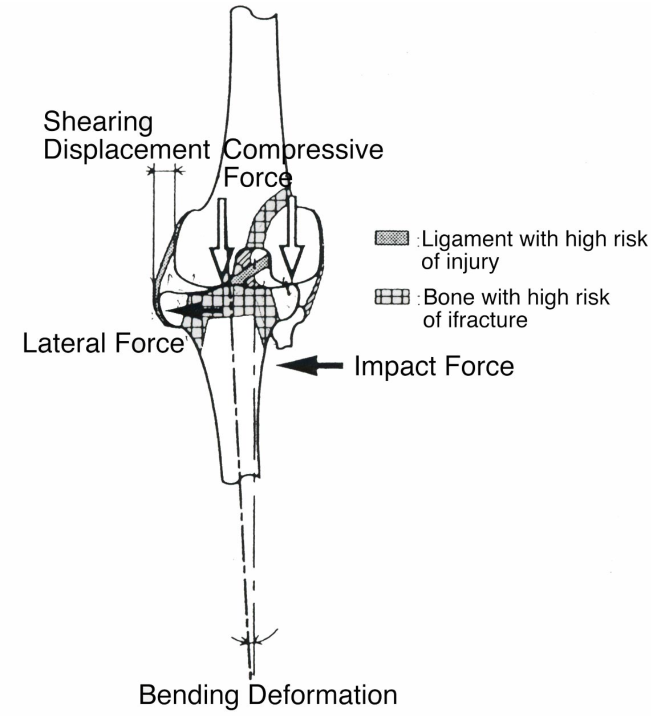

Fig. 4.2 Injuries resulting from shearing-type loading conditions at ram speed of 40 km/h. Based on Kajzer et al. (1997).

4.2.4 Indicators of Injury Risk to Leg and Knee Joint. Suggestions for Biofidelity Requirements for Legform Impactors

Summary of shearing and bending injury mechanisms presented in the previous section suggests that the injury risk to the leg and knee joint can be described by means of the following three variables: 1) shearing displacement (i.e., lateral displacement between proximal leg and distal thigh at the knee joint), 2) knee joint angle (i.e., relative angular displacement between the leg and thigh), and 3) impact force (i.e., force between the leg and object striking it) (Fig. 4.3). It seems reasonable to use these variables in evaluation of the biofidelity of legform impactors.

Corridors (average ± standard deviation) of impact force, shearing displacement and knee angle-time histories for such evaluation have been determined by Matsui et al. (1999) using the PMHS experimental data of Kajzer et al. (1997, 1999). However, the shearing displacement-time histories used by them were derived from displacements of photographic targets located at around 0.05-0.08 m from the knee joint center. This implies that these time histories are only an indirect and not very accurate indicator of lateral displacement between the proximal leg and distal thigh at the knee joint. Therefore, it appears that reliable experimental data for evaluation of biofidelity of legform impactors in terms of shearing displacement-time histories have not been determined yet.

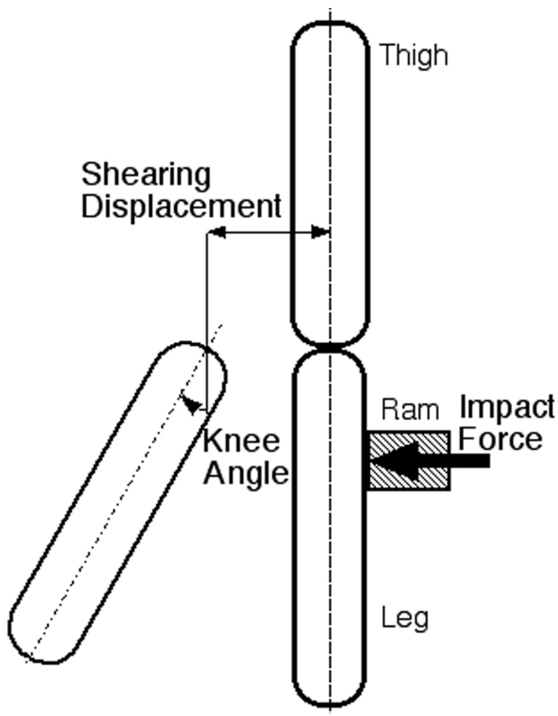

Fig. 4.3 Explanation of shearing displacement, knee angle, and impact force.

4.3 Summary of Mathematical Modeling Work

Mathematical models, complementing the experimental investigations, have been used in understanding the injury mechanisms to the lower limbs, *e.g.*, studies of Yang et al. (1996), Yang (1997), Wittek et al. (2000), and Konosu et al. (2001). In these studies, modeling of impact to the pedestrian lower limbs has been performed by means of rigid body dynamics codes and finite element codes. In rigid body models, the tibia and fibula fractures have been represented by introducing a joint with specific “frangible” properties to connect proximal and distal leg segments (Yang, 1997). Finite element models, on the other hand, make it possible to estimate stress and strain distribution in lower limb bones and soft tissues, which enables one to directly study the effects of tibia, fibula and femur deformation on the overall responses of lower limb. Furthermore, bone fractures and ligament ruptures can be represented by means of various damage models, *e.g.*, Takahashi et al. (2000).

The recent results of finite element modeling of the lower limb by Konosu et al. (2001) suggested that the shearing displacement, bending angle at the knee joint, and proximal leg acceleration can be strongly affected by the tibia deformation. These results need perhaps further consideration when discussing requirements for legform impactor performance as they imply that a deformable leg and thigh might be needed in such impactor.

4.3.1 Computer Simulation of Pedestrian Head Impacts

Computer simulation has been used by the Pedestrian Safety Working Group to study the influence of vehicle shape and pedestrian anthropometry and posture on the impact conditions required of sub-system testing. These impact conditions are the mass, speed and angle of the subsystem impactors, with reference at this stage to the reconstruction of head impacts involving a 50th percentile male. Computer simulation also shows promise for use in the study of possible interactions between the results of subsystem tests. For example, is it possible that a particular measure that reduces the risk of a severe injury to the knee joint may increase or reduce the risk of a severe head injury?

Front shape of passenger car was investigated and categorized into three groups, Sedan, SUV (Sport Utility Vehicle) and 1-Box (One Box Vehicle), so that the effect of vehicle front shape on the pedestrian impact was studied with computer simulations focusing on the head impact velocity, head impact angle, WAD (Wrap Around Distance) and head effective mass.

Figure 4.4 shows the car front shape corridors for the three groups obtained from current production cars in Europe, Japan and U.S. Each corridor consists of upper and lower boundaries of the bonnet and windscreen glass with the front skirt corridors.

Figure 4.5 shows the definitions of the measuring points for the bumper lead (BL), bumper center height (BCH), leading edge height (LEH), bonnet length, bonnet angle, windscreen angle, and the bottom depth and height of the front skirt. These positions and angles for the lower, middle and upper boundaries of the corridors for each group are summarized in Table 4.1.

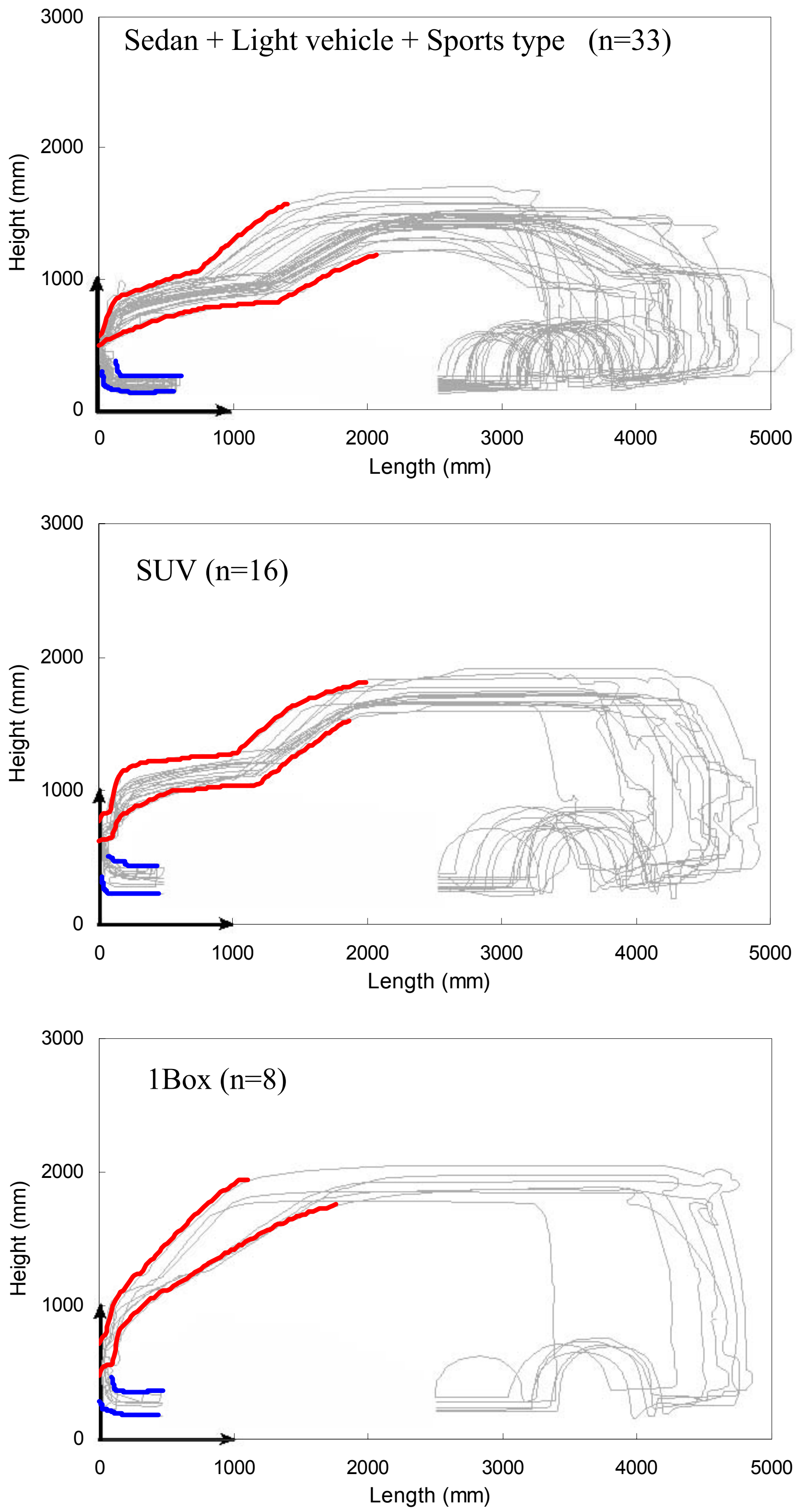

Figure 4.4 Car Front Shape Corridors

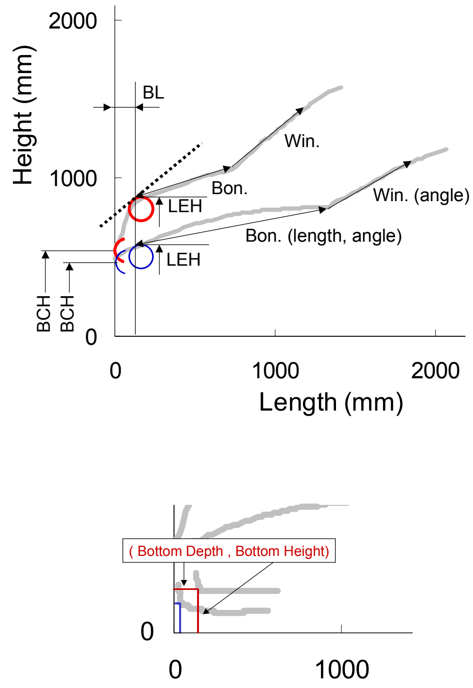

Figure 4.5 Definitions of Car Front Shape

Table 4.1 Car Front Shape Corridors

Sedan + Light vehicle + Sports type				
		Lower	Middle	Upper
BL	(mm)	127	127	127
BCH	(mm)	435	475.5	516
LEH	(mm)	565	702	839
Bon. length	(mm)	1200	917.5	635
Bon. angle	(deg.)	11	14.5	18
Win. angle	(deg.)	29	34.5	40
Bottom depth	(mm)	42	98	154
Bottom height	(mm)	182	225.5	269
SUV				
		Lower	Middle	Upper
BL	(mm)	195	195	195
BCH	(mm)	544	640	736
LEH	(mm)	832	1000	1168
Bon. length	(mm)	1023	933.5	844
Bon. angle	(deg.)	11	9.75	8.5
Win. angle	(deg.)	36	39.5	43
Bottom depth	(mm)	48	123	198
Bottom height	(mm)	248	348	448
1Box				
		Lower	Middle	Upper
BL	(mm)	188	188	188
BCH	(mm)	448	576	704
LEH	(mm)	864	1004	1144
Bon. length	(mm)	361	259	157
Bon. angle	(deg.)	40	40	40
Win. angle	(deg.)	30	38	46
Bottom depth	(mm)	63	95	127
Bottom height	(mm)	214	292.5	371

The pedestrian-vehicle simulations that have been performed have made use of rigid body dynamic codes such as MADYMO (TNO, Delft, the Netherlands) in which the pedestrian is represented by a tree structure of rigid links, connected with kinematic joints. Properties of the model that are specified include the mass and moments of inertia of each link, the properties of the kinematic joints, the geometry of the contact surfaces of each link and their contact properties. The front of the vehicle, back to the upper frame of the windscreen, is similarly described.

The properties of such models are based on studies of the joints and body segments of post-mortem human subjects and/or human volunteers. The behaviour of the model can be validated by confirming that its response is similar to the response of human joints and body segments when subjected to dynamic loads in experiments. Pedestrian models can also be compared to the kinematics of post mortem human subjects subjected to experimental impacts by a vehicle and also to the results of detailed investigations of actual pedestrian-vehicle collisions in those cases in which a reasonable estimate of the impact speed of the striking vehicle is available.

Three computer models have been used by the Japan Automobile Research Institute, the United States National Highway Traffic Safety Administration, and the Road Accident Research Unit of Adelaide University, Australia, for the purposes of this Working Group. Each of the models was used to simulate experiments with cadavers, to ensure that the kinematics of the model was reasonably bio-fidelic. The results for three output parameters relating to head impacts with the bonnet, where relevant, and the windscreen are summarised in Tables 4.2 to 4.4 for three categories of vehicle frontal shape. These parameters are:

(1) Head impact speed divided by the vehicle impact speed
(2) Head impact angle
(3) Headform effective mass divided by the actual mass.

Table 4.2
Head impact speed/impact speed for bonnet and windscreen head impacts by type of vehicle (50 percentile male)

Vehicle Type	**Head Impact Speed/Impact Speed**	
	Bonnet Impact	**Windscreen Impact**
Sedan	0.81 ± 0.17[1]	1.06 ± 0.13
SUV	0.71 ± 0.21	0.96 ± 0.07
1 Box	no contact	0.68 ± 0.21

Notes: [1] One Standard deviation

Table 4.3
Head impact angle for bonnet and windscreen head impacts by type of vehicle (50 percentile male)

Vehicle Type	Head Impact Angle (with horizontal)	
	Bonnet	Windscreen
Sedan	60.6 ± 14.4[1]	43.5 ± 7.9
SUV	77.9 ± 19.3	68.5 ± 7.5
1 Box	no contact	45.1 ± 9.5

Notes: [1] One Standard deviation

Table 4.4
Head effective mass/actual mass for bonnet and windscreen head impacts by type of vehicle

Vehicle Type	Head effective mass/actual mass	
	Bonnet	Windscreen
Sedan	1.01 ± 0.13[1]	0.79 ± 0.23
SUV	0.99 ± 0.35	0.84 ± 0.20
1 Box	no contact	0.76 ± 0.30

Notes: [1] One Standard deviation

4.3.2 Effective Head Mass

While it has been concluded that the acceleration of the head solely by a force acting through the neck is most unlikely to result in injury to the brain, (Meaney et al, 1994; Mertz et al, 1997) it may have implications for the effective mass of the head on impact with the car.

During the collision between the car and the pedestrian, the head is accelerated by forces acting on it through the neck. Commonly, this acceleration causes the head to move toward, and to strike the upper surface of the vehicle. During the impact, forces will still be acting on the head from the neck. These forces acting through the neck may affect the impact between the head and the surface of the vehicle by combining vectorially with the impact force. The component of the neck force that is collinear (acting along the same vector) with the contact force will influence the acceleration of the head along that vector. The component of the neck force which is perpendicular to the contact force vector will not affect the acceleration of the head in the direction of the contact force.

Clearly, the effect of any forces acting through the neck cannot be directly included in a sub-system test in which the head is represented by a free-flight head form striking the upper surface of the vehicle. However, the contribution of the neck may be seen as being equivalent to adding to, or subtracting from, the mass of the head during the contact with the bonnet.

The greater the component of the neck force that is collinear with the contact force, the greater the influence the neck force will have on the "effective" mass of the head during its impact with the surface of the vehicle. If the force acting in the neck is a tensile force, then the component collinear with, but opposed to, the contact force will have the effect of reducing the total force acting along that vector, thereby, from F = ma, giving the impression that the head has a lower mass than it actually does. Conversely, if a compressive force is acting in the neck when the head hits the car, as may happen if the body is aligned with the impact force vector and the impact is on the top of the head, the two forces are added together, giving the impression that the head is heavier than it actually is.

The effective mass of the head may be derived from a computer simulation of a pedestrian-vehicle collision by dividing the impact force by the acceleration of the head in the direction that this impact force is acting. (The results of the effective head mass calculated from the computer simulations presented elsewhere in this Chapter have been based on the resultant acceleration of the head, not that component collinear with the impact acceleration or force. This will be considered further by the IHRA Pedestrian Safety Working Group.)

In practice, the relationship between effective and actual head mass depends on several factors, notable the frontal profile of the striking vehicle. In some cases the effective head mass will be less than the actual mass, in other cases it will be greater.

There is considerable variation in the estimates obtained from the three computer models for the parameters listed in Tables 4.2 to 4.4, as indicated by the standard deviations for certain impact conditions. This is despite the fact that each model could replicate the kinematics of a cadaver in simulations of laboratory controlled pedestrian collisions. Although average values are presented in these Tables, considerably more work is required to understand the reasons for the differences in the results obtained from the three computer models with a view to, in due course, settling on one model to guide the further development of subsystem testing for pedestrians of varying stature.

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CHAPTER 5: EXISTING TEST METHODS & TOOLS

5.1 Introduction

The IHRA pedestrian accident data set (see Chapter 3) shows that for children (age < 16) the head, lower leg and upper leg are most frequently injured (AIS2+) by a part of the vehicle. The top surface of the bonnet/wing is the leading cause of injury, followed by the front bumper. For adult pedestrians (age > 15) the head, lower leg and chest are most frequently injured by a part of the striking vehicle. The front bumper is the leading cause of injury, followed by the top surface of the bonnet/wing and the windscreen glass.
The IHRA Pedestrian Safety WG decided to give priority 1 to the body regions adult head and child head to be included in a possible test procedure. Priority 2 was given to the adult knee and lower leg area. All other body areas would be considered later, including chest, abdomen, pelvis and upper leg.
When the IHRA Pedestrian Safety WG started their mandate, suitable pedestrian dummies were not available. Hence, the IHRA Biomechanics working group was inquired of the possibility of development of pedestrian dummies. Their reply was that this possibility was very low because of the long development time and the extensive costs. Also, pedestrian dummies have many disadvantages for use in test methods intended for use in regulations to assess pedestrian protection. The most significant disadvantage is the need for a whole family of dummies to represent the range of real life statures found. The dummy statures would need to cover from a small child through a large adult if the whole area of the car likely to be hit is to be tested. Consequently, the IHRA Pedestrian Safety WG decided to adopt the sub-system method, as already adopted in other test procedures, such as ISO/TC22/SC10/WG2 and EEVC/WG17. It was also decided to cover a wider range of vehicle shapes, speeds and test areas (including e.g. windscreen and A-pillars) than specified in these existing test methods.

5.2 EEVC Test Methods

In the European Union more than 7000 pedestrians and 2000 pedal cyclists are killed every year in a road accident, while several hundred thousands are injured. A large proportion of pedestrians and cyclists are impacted by the front of a passenger car. This was recognised by the European Enhanced Vehicle-safety Committee (the former European Experimental Vehicles Committee) and several studies in this field were performed by Working Groups of EEVC [EEVC 1982, EEVC 1984, EEVC 1985]. Based on this research various recommendations for the front structure design of passenger cars were developed. Moreover, test methods and regulations have been proposed to assess pedestrian protection. In the spring of 1987 one of these proposals was discussed by the EEC ad-hoc working group ‘ERGA Safety’ [Commission of the European Communities 1987]. It was concluded that the basis of the proposal was promising, however, additional research was needed to fill up some gaps. The EEVC was asked to co-ordinate this research and at the end of 1987 EEVC Working Group 10 ‘Pedestrian Protection’ was set-up.

The mandate of this group was to determine test methods and acceptance levels for assessing the protection afforded to pedestrians by the fronts of cars in an accident. The test methods should be based on sub-system tests, essentially to the bumper, bonnet leading edge and bonnet top surface. The bumper test should include the air dam; the bonnet leading edge test should include the headlight surround and the leading edge of the wings; the test to the bonnet top should include the scuttle, the lower edge of the windscreen frame and the top of the wings. Test methods should be considered that evaluate the performance of each part of the vehicle structure with respect to both child and adult pedestrians, at car to pedestrian impact speeds of 40 km/h. The different impact characteristics associated with changes in the general shape of the car front should be allowed for by variations in the test conditions (e.g. impact mass and velocity, direction of impact).

EEVC WG10 started its activities in January 1988. A programme was set-up intended to develop the required test methods as described by the mandate. The studies necessary to develop test methods have been summarised in a first report of EEVC WG10, presented to the 12th ESV Conference in 1989 [EEVC 1989]. These development studies included full-scale dummy tests, cadaver tests, accident reconstructions, analysis of accident data and computer simulations. Furthermore the developed test proposals had to be tested against representative cars of current designs to determine the feasibility of the proposals. The compatibility with existing regulations, other safety features and basic operational requirements for cars was assessed. These studies were performed in 1989/1990 by a European consortium acting under contract to the European Commission (EC) and under the auspices of EEVC. The consortium consisted of BASt, INRETS, LAB/APR, TNO and TRL. The studies were completed in June 1991 and were summarised individually in technical reports [Janssen and Nieboer 1990, Janssen et al. 1990, Lawrence et al. 1991, Glaeser 1991, Cesari and Alonzo 1990, Brun-Cassan 1991]. The summary report [Commission of the European Communities 1991] included an Annex called “Frontal surfaces in the event of impact with a vulnerable road user - proposal for test methods”. This work was also summarised in a second EEVC WG10 report, presented to the 13th ESV Conference in 1991 [EEVC 1991].

The third and final report of EEVC WG10 was written in 1994 [EEVC 1994] and focused especially on the changes and improvements with respect to the previous version of the proposed test methods, as described in [Commission of the European Communities 1991] and [EEVC 1991]. The test methods were up-dated and included in the Annex “Frontal surfaces in the event of impact with a vulnerable road user-proposal for test methods”. Also general background information was given and choices explained. Working Group 10 was dissolved in November 1994. A summary of the 1994 final report and an overview of the activities performed by the former members of WG10 since the end of 1994, was presented in 1996 to the 15th ESV Conference [EEVC 1996].

In May 1997 the former members of EEVC WG10, on request of the EEVC Steering Committee, met again to discuss technical progress and new developments with respect to the EEVC pedestrian protection test methods. Based on these discussions the Steering Committee decided in June 1997 to set-up a new EEVC working group -WG 17 Pedestrian Safety- with two main tasks:

1. Review of the EEVC WG10 test methods (final report 1994) and propose possible adjustments taking into account new and existing data in the field of accident statistics, biomechanics and test results.
2. Prepare the EEVC contribution to the IHRA working group on pedestrian safety.

The EEVC WG 17 activities with respect to task 1 were finalised early 1999 and the EEVC report was supplied to the EC as requested [EEVC 1998]. Improvements were proposed with respect to the test procedure, definitions, tools and requirements. The EEVC test methods were used by the European Commission as basis for further discussions on an EC Directive in this field.

Figure 5.1 shows the EEVC pedestrian protection sub-system test methods. The EEVC test methods include in order of priority:

1. Child headform to bonnet top tests
2. Adult headform to bonnet top tests
3. Legform to bumper tests (for all normal height bumpers (up to 500 mm lower bumper height) for high bumpers an optional, alternative upper legform to bumper tests is available)
4. Upper legform to bonnet leading edge tests

The methods fully describe the procedures for testing, the tools (including certification) and (proposed) test requirements or criteria.

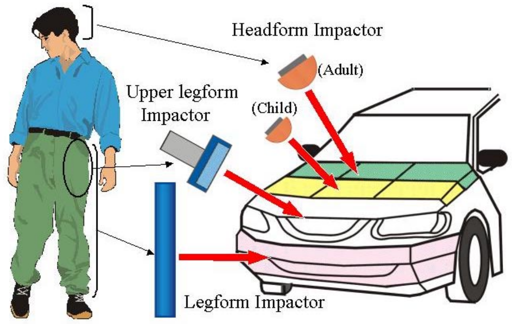

Figure 5.1. EEVC pedestrian protection sub-system tests

5.3 ISO Test Methods

The International Organization for Standardization created a pedestrian protection working group (ISO/TC22/SC10/WG2) in 1987 to develop test methods used for developing pedestrian friendly cars. The membership of the working group is comprised of worldwide experts from Australia, Europe (Germany, France, U.K., Italy and Sweden), Japan, and U.S. The working group has been focussing on the adult legform test and the child/adult headform tests, since leg injuries were very common found and head injuries are life threatening in a car-pedestrian accident. Existing pedestrian protection test methods, including EEVC and NHTSA test procedures were studied and worldwide accident data analysis and computer simulations were conducted.

The proposed ISO test methods were based mainly, with some changes, on existing EEVC test methods as described in the previous paragraph. The mandate for ISO/WG2 is to produce test methods suitable for reproducing an accident at any car-impact speed up to 40 km/h. This differs from the EEVC mandate, which was to produce test methods that reproduce an accident at 40 km/h. However, the current ISO legform test procedure is suitable for tests up to 20 km/h, since biomechanical data for the legform test above 20 km/h were not available. The difference of the mandates is one of the reasons for some of the differences between the ISO and EEVC procedures.

It is likely that the ISO working group will consider developing procedures for other impact phases of a pedestrian accident. It appears less likely that ISO will adopt the EEVC upper legform to bonnet leading edge test method. Instead they may opt to develop procedures for child and adult thorax.

5.4 Tools

The IHRA Pedestrian Safety WG identified the following tools for possible sub-system tests:

- EEVC WG10 and WG17 adult and child headforms developed by TNO
- ISO WG2 adult and child headform specification
- NHTSA adult headform
- NHTSA child chest impactor
- EEVC upper legform impactor developed by TRL
- EEVC WG10 and WG17 legforms developed by TRL
- ISO legform developed by JARI/JAMA
- ISO legform developed by NHTSA (using a friction system for lateral knee bending instead of the deformable elements used in the other designs)

It was decided to assess these tools in terms of application, complexity, anthropometry, biofidelity, repeatability/reproducibility, sensitivity, durability, handling/functionality, certification, costs and status/availability. Depending on the specifications of the IHRA test methods one or more of these tools could be adopted and other impactors could be devised for other pedestrian body areas requiring protection.

Both the EEVC and ISO headform tests make use of a free-flight headform which mass is intended to match the effective mass of a human head, when the head impacts a vehicle in a pedestrian accident. However, the ISO adult headform mass of 4.5 kg differs from the EEVC headform mass of 4.8 kg. The EEVC study of computer simulations and dummy tests concluded that the effective mass for adult head is heavier than the head mass itself and an additional 0.3 kg is required to account for the forces acting through the neck during the head impact. EEVC confirmed this mass as appropriate by reconstructing the head impacts seen in cadaver tests with the 4.8 kg headform impactor, which gave very similar HIC values and acceleration time histories. For the child EEVC concluded that the neck forces relieved the head impact, so the effective mass for a 6-year old child head is 1 kg less than the head mass itself, resulting in the selection of a headform impactor mass of 2.5 kg.

The EEVC and ISO studies using computer simulations indicated that the effective mass for both the adult and child heads impacting a vehicle is greatly affected by the impact conditions, such as vehicle shape and stiffness. The ISO/WG2 concluded that an average value of effective head mass from a large number of computer simulation runs is almost identical with their respective head mass itself for both the adult and child heads impacting a vehicle and therefore selected the actual adult and child head mass for their impactors. On the contrary, the EEVC decided it was better to cater for a typical worst case rather than an average value. Through the discussions in the IHRA/PS/WG, it is stated that the most appropriate method of calculating head effective mass should be found since the EEVC and ISO studies used different methods.

In addition ISO are proposing a diameter which matches that of a 6-year old child head, but EEVC decided to scale down the adult impactor diameter to produce the required child mass thus standardising the designs. This results in the EEVC child headform impactor being a smaller diameter than that of the average 6-year-old child.

The ISO procedure for the legform to bumper test method has been accepted as a draft procedure. The main difference between the ISO and EEVC test methods is in the lateral knee joint stiffnesses in bending and shear and the methods of specifying them. However, the latest biomechanical data (Kajzer et al, 1997) appears to indicate that the bending stiffness is too low and that the EEVC requirements are more appropriate. The biomechanical tests by Kajzer were to the legs of complete cadavers, restrained via force transducers fixed to the top and bottom of the femur bone, where the leg was impacted laterally by a representation of a bumper. In legform biofidelity tests by Matsui (Matsui, Y, 1999) where the ISO, EEVC and JARI legforms were subjected to a similar test to those of Kajzer, described above, the ISO legform was found to be the least biofidelic.

Dummies have been used in pedestrian safety research for more than 25 years, including modified versions of Hybrid II and III, and the Rotationally Symmetrical Pedestrian Dummy (RSPD) with a single leg and a specially constructed knee (Kajzer, 1989). However, they produced kinematics that were different from that observed in PMHS tests (Kallieris, 1988). In addition, there were sometimes problems in durability and repeatability.

A pedestrian dummy, called Polar (see Figure 5.2), has been recently developed in a joint collaboration of GESAC, Honda R&D, and JARI (Akiyama, 1999). The first version of Polar, now called Polar I, was modified from Thor, the NHTSA frontal dummy. The modifications were specially designed to improve the kinematics response during lateral impact with a vehicle at different impact speeds. The latest version of the dummy is known as Polar II and includes a more human-like representation of the knee, a flexible tibia, and a more compliant shoulder. Polar II has been recently tested in full-scale impacts by NHTSA and the results will be presented at the IHRA/PS/WG.

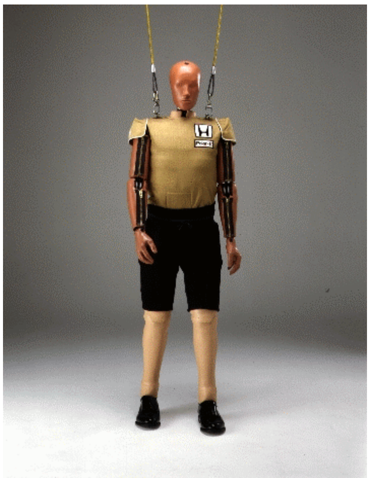

Figure5.2. Frontal view of Polar pedestrian dummy.

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CHAPTER 6: TEST METHODS – Scientific Background

When the working group on pedestrian test procedures started, it was stated that the development of harmonised test procedures would be based upon real world crash data.
According to the analysis of accident data from the different countries involved in the project (Australia, Europe, Japan and the US), which is presented in chapter 3, the IHRA/PS working group decided to give priority number 1 to the adult head and child head, to be included in possible test procedures. As a matter of fact, the accident data indicate that the head is the most common site of fatal injuries to a pedestrian struck by a passenger car, these injuries resulting from impacts with the vehicle front structure, including the windscreen and the A-pillars (IHRA/PS/10,11,12,16,17,26,34,44,45,47,48).

Priority 2 was given to the adult leg.
All other body areas such as abdomen, pelvis, chest, upper limbs…. will be considered later.

6.1 Introduction

From the available scientific background, IHRA/PS decided to produce simple and repetitive test procedures.

Initially, impact tests using a pedestrian dummy were considered. However, some significant disadvantages of pedestrian testing using dummies for regulatory purposes became apparent. The repeatability of tests using pedestrian dummies is relatively poor, small variations in the initial set-up will have an increasing influence on the impact severity and localisation on the car of the impacts of the different body parts. Also if pedestrian dummies were used, then a range of pedestrian dummies of different statures would be required to test all areas likely to be hit in real life. The dummy statures would need to cover from small children through large adults if the whole area was to be tested. This is because the impact locations for key body parts such as the head are very dependant on the pedestrian stature as well as the position of first contact across the vehicle width and the pedestrian's motion before contact. It would also be very difficult to predict and control the impact locations of dummy body parts to test selected danger points accurately, particularly for the head.

For test methods intended for extensive and possible legislative use, as in this case, sub-system test methods would overcome these disadvantages. Sub-systems tests have the following advantages over full-scale dummy tests:

- they can easily be used to test the whole area likely to be hit by the pedestrians,
- they can be aimed accurately at selected danger points,
- they give good repeatability and durability,
- the tests are less complex and require less testing space, since the car remains stationary,
- the tests cost less to perform,
- the test requirements are simpler to design for and model mathematically,
- they can be more easily used in component developments for the cars,
- the test severity can be adjusted to take into account practical design limitations.

Also the problems of durability of the test tool were taken into account; the complete dummy is more fragile than the sub-systems, and the dummy generally sustains a second impact against the ground after the impact against the car, which can cause severe damages.

So IHRA/PS decided to adopt the sub-systems test methods and to establish specifications. That means that test procedures were drafted for each of the sub-systems. Two headforms are proposed for use in sub-system testing, one to represent an adult pedestrian head and one to represent a child pedestrian head. They are defined as falling in the height range of typical adults or children respectively, therefore some short adults are included in the height range of children and the reverse, some tall children included in the height range of adults.
The head-form test procedures are such that the car is subject to performance rather than design criteria.

6.2 Principles of provisional IHRA headform impact conditions

The child and adult headform test zones (Child = 900mm to 1700mm WAD Adult = 1400mm to 2400mm WAD) were selected from the range of actual head impact locations in real accidents involving children and adults. Typically, IHRA have classified children as those up to 15 years old and adults as those over 16 years old. Obviously, within these child and adult classifications there will be a range of statures, and a pedestrian's stature is the most significant factor effecting how far back on a car their head strikes. Therefore, these zones affectively represent the range of child and adult statures hit by cars. The IHRA Working Group have selected one size of headform to represent all children and one size to represent all adults. This simplification was made on the grounds that for each group there is a comparatively small variation in head mass, particularly if very young children, who have a low accident rate, are excluded. However, a pedestrian's stature and the vehicle shape are thought to have an effect on the head impact velocity, impact angle and vehicle part hit. For example, with one vehicle shape the head of a small child might impact the bonnet at front of the child zone at one velocity and angle. For the same vehicle shape the head of a large child might impact the bonnet at the rear of the child zone with a higher impact velocity and angle. A smaller car, with a different shape, hitting the small child might result in a head impact to the back of the bonnet and the head of the large child might impact the windscreen. Therefore, the impact conditions in the child and adult headform test methods need to reflect these two factors. This is achieved in the provisional test methods by using vehicle shape, and sub wrap around zones in the child and adult head test areas. The test vehicle is classified into one of three shape categories: sedans, sports utilities or one box, using shape templates. For each vehicle shape category, headform velocity and impact angle will then be found from a look-up table for bonnet and windscreen contacts. Sub wrap around zones will be specified in the table so that within the child or adult zones the effect of variations in stature can be reflected by different test conditions (velocities and angles). The number of sub-wrap around zones required will depend on the sensitivity of impact conditions to stature. To complete the child and adult look-up tables it is intended to determine the impact conditions from computer simulation results of various vehicle shapes and pedestrian statures. However, as discussed in Chapter 4, there is considerable variation in the estimates obtained from the three computer models used to date. Also, at the time of this report, only adult simulations have been completed. Therefore no child impact conditions are given in the child test method look-up table and the adult impact conditions are provisional.

6.3 Head-form specifications

Mathematical simulations of adult head impact against different categories of shapes of cars, defined previously, were performed. They focused on head effective mass, head impact speed and angle at impact, and also wrap around distance at the head contact point, as described in chapter 4.

Mass and dimensions

The results of these simulations indicated that the effective head mass of the head varied throughout the contact period and so some averaging of the effective mass function over the relevant impact period was required to determine a single value for the effective mass. The simulation results also showed a large variation in head effective mass depending on vehicle shape. Within the test method, it was also clearly undesirable to require head-forms of different masses for vehicles of different front shapes, as IHRA/PS wanted to produce simple and repetitive test procedures.

It was noted that for the average effective mass for all vehicle shapes simulated was almost comparable to the head mass itself for cases of bonnet contacts, whereas the average effective mass is about 80 percent of the head mass for cases of windscreen contacts (IHRA/PS/185) (IHRA/PS/166). Therefore, based on this and engineer judgment, IHRA/PS decided to take the average effective mass for all vehicle shapes and to specify only one value of mass for an adult head-form and one value for a child head-form.

The mass for the adult head-form was chosen to be 4.5 kg, which is the mass of the head of the 50th percentile male human being (which is also the mass typically used for the head of the 50th percentile male dummy) (IHRA/PS/150). This is the total impactor mass including instrumentation.

Based on studies of human head dimension, a diameter of 165 mm was chosen both in EEVC and ISO test procedures. This value was reportedly based on existing documents including SAE J921 and was considered to represent the diameter mainly of the forehead portion (impact area rather than the maximum outer diameter of the head). The value of the adult head-form diameter has to be considered again in this group.

The distribution of pedestrian victims by group of age indicates that the age group around 6 years old has the highest frequency of pedestrian accidents involvement at nearly 14 percent of all the cases. For this reason, it was decided to consider a head-form representing the head of a six years old child.

According to the recommendations of ISO working group of Biomechanics (ISO/TC22/SC12/WG5), the average mass of the six year old child head is 3.48 kg (which is from 6-year child Hybrid III dummy data, SAE paper 973317), which has been rounded to 3.5 kg. IHRA decided to also select 3.5kg for the mass of the child head-form.

The only data available for the dimensions of a 6-years old child head are the circumference of the head which is 523 mm, the width which is 141 mm and the A-P length which is 180 mm (Ref: ISO/TC22/SC12/WG5 Document N535 – Irwin and Mertz, "Biomechanical Bases for the CRABI and Hybrid III Child Dummies", 41st Stapp Car Crash Conference, SAE 973317, November 1997 (IHRA/PS/173). From these values one can determine the diameter, either by taking the average of the two dimensions, A-P and width, (141+180)/2 =161 mm or from the circumference, which leads to a value of 166 mm. So it is decided, for the child head-form, to use a diameter of 165mm.

Moments of inertia

As regards the moments of inertia, it was mentioned that the value specified by EEVC ($0.0125 \pm 0.001 kg.m^2$) is about half the value of the cadaver data, and that therefore a review was required. A value of $0.0239\ kg.m^2$ was reported for the adult head in study on "the influence of moment of inertia head-form impactors" submitted by Japan at ISO/TC22/SC10/WG2. However, it was thought possible that achieving other more important head-form requirements might conflict with achieving this - design to determine the best achievable moment of inertia value is conducted, after a thorough investigation is completed on the head-form mass and geometrical properties.

It was decided to set this as a subject for future study, since considerable difficulties are foreseen in conducting such an investigation which would include several other specifications of the head-form impactor.

Taking into account the present stage of development and using the regression curve derived from human body data, dummy data and MADYMO/GEBOD computer simulation data (ISO/SC10/TC22/WG2/N627), the moment of inertia was determined from the mass distribution found from child and adult anthropometrics data respectively.

The experts of this group agreed that efforts be made to attain values as close as possible to the following human values :

for the adult head : 0.0239kg.m^{2,}

for the child head : 0.0151 kg.m^2**.**

However, it may be difficult to achieve these values in practice.

As regards these two head-forms, the study priorities are mass, centre of gravity and accelerometer placement at the centre of the sphere and vibration characteristics.

It is anticipated that moment of inertia may need to be adjusted for practical considerations.

6.4 Test procedures

The test procedures are based on the accident statistics, the results of the computer simulations, cadaver tests and engineering judgment. The latter is applied to create sufficiently simple and repeatable test procedures suitable for use in regulations.

According to the accident data of Europe, Japan and the US (IHRA/PS/179), the 50th percentile impact speed between a pedestrian and a car was 25-30 km/h. For the injury level of AIS 3 or over, the corresponding speed was 50-55 km/h. According to the accident data of Australia (IHRA/PS/103), the 50th percentile impact speed was 50-60 km/h

On the other hand, a PMHS test for adult indicated that such ratio for the head impact speed against car impact speed varies widely between 80 percent and 150 percent (IHRA/PS/198).

The values for the adult head impact speed related to the vehicle impact speed in simulations of a head collision with the bonnet or the windshield show significantly different results according to the simulation model and vehicle shape used; the average ratio varies significantly from 0.7 to 1.1 according to vehicle shape. Also, there are differences between contacts on the bonnet and contacts on the windscreen, due to the big differences in terms of impact conditions.

So at this time, the IHRA/PS working group agreed to use 1 std values instead of average. Consequently, current velocity values in the adult test methods are provisional and further simulations are required before they are finalised.

Simulation studies for the child have yet to be carried out so child test velocities have yet to be established.

IHRA/PS decided that the test methods should replicate car speeds of 30, 40 or 50 km/h and the head speed ratio will be applied to the car speed to find the impact speed for the head-form.

Discussions on impact speed from the car feasibility standpoint will be reported in another chapter.

Concerning head impact angle, the simulations performed with the different models for the adult head lead again to a wide range of results but the average angle was 71 degrees, while an average of 65 degrees was reported for the PMHS (IHRA/PS/198).

The head impact test areas on the vehicle, defined on the basis of wrap around distances for the child and adult headforms correspond to the areas that accident data shows are commonly struck by the head of a child and an adult pedestrian respectively. The final WAD value derived from the accident data of Australia, Europe, Japan and the US was 900-1700 mm for child head-form and 1400-2400 mm for adult head-form. Consequently a WAD 1400-1700 mm was shared by both adult and child head-forms and was named “transition zone”.
The methods of marking the WAD reference lines are described in Appendix D and E.
The provisional values for adult head impact velocity, impact angle and wrap around distances are given in Appendix D which describes the test conditions for the different categories of vehicle shapes and according to the fact that the impacts are on the bonnet or in the windshield.
However, the IHRA/PS have concluded that further simulations are required before the final head-form impact velocities and angles can be chosen.

6.5 Injury criteria

For the purpose of this working group, emphasis has been placed on pedestrian head injuries resulting from head impact with the vehicle frontal structure, including the windscreen and the A-pillars. The HIC has been selected as the measure of the risk of brain injuries resulting from such an impact.
HIC has been selected, despite the fact that it doesn’t take into account the influence of some factors such as the rotational acceleration of the head, because it is used universally in crash injury research and prevention and the threshold was set at a current 1000 after consideration of existing threshold values and the new values being studied by NHTSA.
Taking into account the short duration of this type of head impact, the time window for the HIC calculation has been set at 15 ms. Due to the short duration of the head-form impact with a car, a HIC window of 15ms will normally give the same result as a window of 36 ms, but the 15 ms window will help to reduce the risk of signals from spurious secondary impacts being accidentally included in the calculation.

Conclusion

At this time, draft test procedures are proposed, but IHRA/PS is aware that considerable work of research and development is still required to refine these test procedures.
Problems were encountered with the simulations and some limitations appeared such as a limited number

of cadaver data to validate the models. Also only one stature of pedestrian was simulated; it would be necessary to simulate other statures, including small and large adults and small and large children.
Temporally, the current results are used in the draft test method for the adult, no values are currently available for the child head test method.

Note

The summary of tests method formulation by the IHRA Pedestrian Safety WG is above.
For each explanation having no IHRA reference, please refer to the minutes compiled by the IHRA/PS/WG as listed below: IHRA/PS/33, IHRA/PS/54, IHRA/PS/74, IHRA/PS/97, IHRA/PS/115, IHRA/PS/156, IHRA/PS/180, IHRA/PS/194 and IHRA/PS/200.

CHAPTER 7: IMPLICATIONS FOR REGULATIONS

(A) SOCIETAL AND ECONOMICAL

7.1 Introduction

It has been estimated that in the year 1999 nearly 900,000fatalities and about 30 millions casualties were sustained in worldwide road accidents (Jacobs *et al*, 2000). Overall it is estimated that casualty numbers will continue to increase over the next two decades. About 45% of the fatal casualties were pedestrians (Jacobs, 2001) with the proportion being highest in the less-motorized countries. Therefore measures to make vehicles less injurious to pedestrians in accidents can result in significant societal benefits worldwide. Detailed accident data for the UK show that approximately sixty percent of these pedestrian casualties were struck by the fronts of cars. The design of car fronts can be improved to reduce the frequency and severity of pedestrian injuries, as has been demonstrated by much research worldwide, for instance by Yoshida *et al* (1999). These measures are also suitable for application to larger vehicles. The aim of this chapter is to estimate the potential benefits in terms of casualty reductions, from vehicles that have been made to meet the pedestrian impact test requirements under development by this Working Group. Measures to protect pedestrians will also be of some benefit to other vulnerable road users such as pedal cyclists and motorcyclists.

7.2 Method and Results

The aim of the Working Group is to produce test methods suitable for the whole of the vehicle front likely to strike a pedestrian. The test methods are intended for cars, vans and utility vehicles. Test tools to represent all the important body regions will also be developed and criteria set with the aim of preventing life-threatening injuries, fractures and joint injuries likely to result in long-term disablement. Currently this work is incomplete, but for the purpose of producing estimates of the potential benefits it has been assumed that the development of the test methods has been completed and the vehicle types within the intended scope have been replaced with compliant vehicles.

The benefit calculation uses *historical* accident data to estimate the effect on *future* accidents that would be expected to occur from implementation of the test methods. In looking at historical data the estimate obtained is of casualties that would not have been injured at that severity had the cars that hit them met the standards that will be required by the test methods. Though not strictly accurate, in what follows these will normally be referred to as casualties ‘saved’.

The protection requirements for the vehicle (crush depth and energy absorption) and the potential reductions of pedestrian casualties are very dependent on the nominal vehicle impact speed selected for the test methods. The speed selected is not necessarily the test speed of a sub-system test to a car, as the impact dynamics of a pedestrian can increase or decrease the impact speed of specific parts of the body. The sub-system test speeds chosen will have ‘equivalent car impact speeds’, and that is what is relevant here. The higher the equivalent car impact speed the larger the benefit but the engineering requirements for the vehicle become more demanding. Therefore, the Working Group is considering a range of equivalent car impact speeds together with the engineering limitations. If the test methods are to be used in legislation, the test speeds are, ultimately, a political decision. Therefore, for these calculations, benefits for three equivalent car impact speeds (30, 40 and 50 km/h) have been derived. The assumption is made at this stage that all tests to different areas of the car will have the same equivalent car impact speed; however this assumption may not continue to hold as the test procedures are finalized.

The resistance to injury of the human frame varies significantly from person to person and with age. Injury criteria are typically set with the aim of providing protection for all but the weakest of the population. However, as with test speed, if the test methods are to be used in legislation, the injury risk selected is, ultimately, a political decision. The proportions that would be saved and not saved above and below the equivalent car impact speed are dependent on the percentage injury risk used to select the injury criteria, the shape of the injury risk function and the distribution of accident impact speeds. Additional savings may arise in practice because car manufacturers would on average provide more than the minimum protection required in order to ensure that all cars produced are within the requirements, but this has not been included in these calculations. For each impact speed two methods will be used to calculate the proportions of injured casualties that could have been 'saved': a) A simplified assumption that those casualties 'prevented' above the equivalent car impact speed will match those casualties 'not prevented' below. b) An assumption that the safety measures will shift the distribution of the relative proportions of fatalities, seriously injured casualties and slightly injured casualties upward in impact speed. Both methods have their limitations and these will be discussed later. Detailed accident data are required to make these estimates, and this IHRA Working Group has gathered the most recent data available for Germany, Japan, and the USA. The accidents are from years 1985 to 1998, mostly from the later part of that period. These data form part of the IHRA Accident Dataset, which has been described in Chapter 3. Accident data from Australia were added to the Dataset subsequent to this benefit analysis.

The benefit, in terms of the proportional reduction of casualties that could be achieved, will not be the same for all injury severities. A benefit calculation needs to use one or more defined severity categories. The on-the-spot IHRA accident dataset collated by this Working Group contains injury data by Abbreviated Injury Scale (AIS) severity. One alternative, therefore, is to base the analysis on Maximum AIS (MAIS) severities. There are a number of advantages to this approach, as it distinguishes between the very severely injured and those with relatively less serious injuries. However, such an approach would ignore the outcome in terms of death. It was considered that it was important to estimate benefits in terms of lives that could be saved, as that is an important measure to policy makers and to the general public. Moreover, if it is desired to put monetary values on the lives and casualties saved, these are more generally available for categories such as fatalities and seriously injured casualties.

While the harmonised test procedures are not yet finalised, it is likely that they will be designed to prevent most fractures, joint injuries and internal injuries, including brain injuries. Not all of these injuries would require treatment as a hospital in-patient. These injuries, that application of the harmonised test procedures should prevent, approximately correspond with the UN/ECE seriously injured definition, and those of countries using a similar definition, such as the UK. Such serious injuries approximately correspond to the range AIS 2-5, excluding fatal injuries. Serious casualties will then be those in the range Maximum AIS (MAIS) 2-5, again excluding fatalities. Therefore, in this chapter, 'serious' is taken to mean an injury or casualty approximating to the UN/ECE definition, with a serious injury being AIS 2-5 and a serious casualty being MAIS 2-5 but with fatalities excluded.

The remaining, AIS 1 injuries will be slight injuries. Slightly injured casualties are those of MAIS 1, excluding the rare cases of fatalities at MAIS 1. Estimates of the potential changes in slightly injured casualties, due to cars passing the IHRA test procedures, are not made in this study.

The IHRA accident dataset was the primary data source but, as it did not identify fatalities, this information was sought and gratefully received from the organisations that had originally contributed the data. References to the accident dataset hereafter in this chapter refer to the enhanced dataset with the fatalities identified. The list of fatalities obtained from Japan was only of casualties who had died within 24 hours of the accident. Therefore, about 23 percent of the Japanese casualties that would be considered to be fatalities by the generally accepted UN/ECE 30 day definition will be included in the seriously injured category, or possibly even in the slightly injured category, in the Japanese data.

In-depth accident studies tend to concentrate on the more severe accidents. Even where there are no intentional biases, the systems used to inform the investigation team (typically police or hospitals) may not themselves be informed of many of the less severe accidents. The analysis methods used in this benefit study mean that estimates are obtained separately for fatal and serious accidents, so bias towards fatal accidents would not be a problem. However, the serious casualty category covers a wide range of severity, and a bias towards the more severe cases would have some effect on the estimates obtained. However, this kind of bias would be difficult to correct, so no weighting corrections have been made.

Initially these international test methods would mainly affect highly-motorised countries but eventually they would have a worldwide influence. As the less-motorised countries have the highest proportion of pedestrian and vulnerable road user casualties, accident data from these countries should ideally also be considered, however the detailed data required are not available from these countries. Therefore only data from the highly-motorised countries were used.

The scope of vehicles being considered by the IHRA Pedestrian Safety Working Group is wider than just cars. It includes all passenger vehicles except coaches and large buses. In a North American context it could include the pick-ups that are often used for private transport. For convenience this group will be referred to as 'cars' in this chapter.

Because the test methods will cover the complete vehicle front, protection will be provided for all impact locations normally involved in frontal impacts. Injury prevention and injury severity reduction has therefore been assumed only for frontal impacts. The IHRA accident dataset used for part of the analysis includes only frontal impacts. It has been assumed in calculations of potential benefits that injuries caused by ground contacts and in other impact modes will not be prevented. Depending on the test zones that are ultimately selected for each test tool or body region, some extremes of stature (i.e. very small children or exceptionally tall adults) may hit areas with protection intended for other body parts. No allowance has been made for this in these calculations.

The proportional reductions in casualties that could be achieved, if cars were designed to pass test procedures developed by the IHRA Pedestrian Safety Working Group, will be estimated in this chapter. These can then be combined with estimates of the numbers currently injured in any given country or region to estimate the reductions in numbers of pedestrian casualties that might be achieved. If desired, these estimates can, in turn, be factored with casualty cost values to estimate the potential benefit in financial terms.

Estimating the proportional reduction of casualties that could be achieved, by using the proportion impacted within the equivalent car impact speed

As explained above, one alternative method is to base the estimate on the proportion of pedestrians impacted at speeds up to and including the equivalent car impact speed of the test procedures. This was the method used by Lawrence *et al* (1993). This is referred to below as the 'uninjured up to the equivalent car speed' method.

The final estimate is derived from a chain of estimates, starting with all the pedestrians fatally or seriously injured. A proportion of these will be injured by vehicles within the scope of the test procedures, mainly by cars. Of these, a proportion will be injured by the impact type that the test procedures are simulating, namely a frontal impact. Of these, a proportion will be injured within the impact speed range covered by the test procedure. Of these, a proportion of injuries will be caused by the vehicle rather than by the ground. This process is shown in Figure 7.1.

Lawrence *et al* had one further step, the proportion injured by the test area of the car. However, that study was based on the EEVC test procedures, for which the tested zone extended only to the base of the windscreen. As the scope of the IHRA test procedures is all areas involved in frontal impacts with pedestrians, this proportion for the current study is taken to be effectively unity.

Pedestrian casualties with fatal and serious injuries, all vehicles involved

⇓

Of those pedestrian casualties, - those struck by 'cars'

⇓

Of those pedestrian casualties, - those struck by car *fronts*

⇓

Of those pedestrian casualties, - those struck up to equivalent car impact speed

⇓

Of those pedestrian casualties, - those with injuries due to car, not ground

Figure 7.1 Proportion of pedestrian casualties potentially saved

Proportions struck by cars: Given wide variations in the mix of vehicles in different countries across the world, it must be accepted that no single values of proportions of casualties struck by cars can apply across the world, in developing and developed countries. For these calculations, values were obtained from the national statistics of Great Britain, for years 1995-99; the proportions of pedestrians struck by cars were 74 percent for fatalities and 85 percent for seriously injured casualties.

Proportions struck by the fronts of cars: The assumption is made that test procedures would be designed to represent only the main accident scenario, of the pedestrian being hit by the front of the car. The proportions of pedestrians hit by the fronts of cars, of all those hit by cars, have been obtained, again from the national statistics for Great Britain. These record the first point of contact. The proportions obtained were 85 percent for fatalities and 66 percent for seriously injured casualties. For test procedures that include the A-pillars there will be additional benefits for some of those recorded as having been first contacted by the side of the car. These have not been included in these benefit calculations.

Proportions struck within the impact speed range: The cumulative distributions of impact speeds for severities fatal, serious and slight in the IHRA accident dataset are shown in Figure 7.2. This figure can be compared with the impact speed distributions in Figures 3.5 & 3.6 in the Accident Data Chapter. The impact speed range over which the test procedures will offer protection is from zero to the 'equivalent car impact speed' of the test procedures. The working group has agreed to produce test conditions for three equivalent car impact speeds of 30, 40 and 50 km/h. Therefore, the proportions of casualties injured at impact speeds up to and including these speeds are shown in Table 7.1, again for severities fatal, serious and slight.

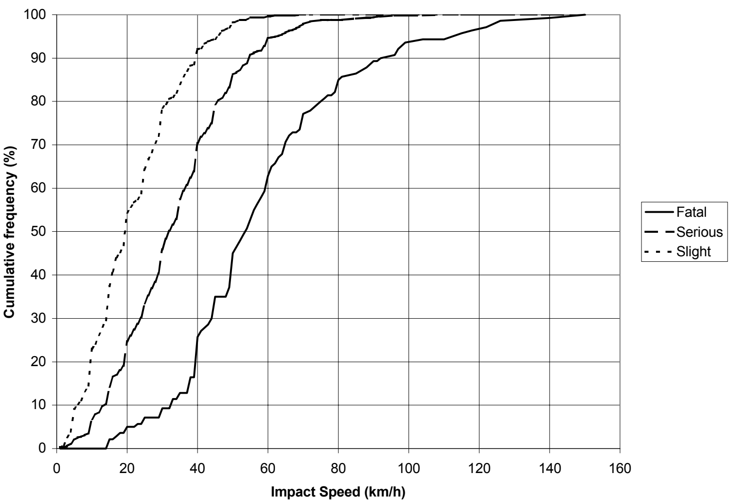

Figure 7.2 Cumulative impact speed distributions by casualty severity

Table 7.1 Cumulative frequency (percent) by impact speed range and casualty severity, for current cars

Speed range (km/h)	Fatal (%)	Serious (%)	Slight (%)
0-30	9	46	79
0-40	26	70	92
0-50	45	86	98

Proportions injured by car not ground: The IHRA accident dataset has, for each injury, the contact location thought to have caused the injury, based on the conclusions of the investigating team. Although this may have often been subjective, these allocations of contact locations have been used for this stage of the benefit analysis. Most of these areas are parts of the car, but there is also a 'road surface' category, referred to here as 'ground'. The analysis procedure can therefore allocate most injuries either to the car or to the ground.

Preventing some injuries to a pedestrian with multiple injuries will not necessarily benefit the pedestrian, or the benefit may be of limited value. It is assumed that impact with an improved car will not affect the likelihood of injury from later impact with the road or the exterior environment generally. Injuries currently occurring from contact with the ground will therefore continue to occur. If the pedestrian should receive a fatal injury from the ground contact then the result will be the same, however much improved the car is. With serious injuries there will be some benefit from preventing individual injuries, but it will not be proportional to the number prevented. To maximise the benefit it would be necessary to prevent all serious injuries, so that the casualty is uninjured or only slightly injured. If a monetary value (casualty cost) is put on a seriously injured casualty, obtaining that benefit would require that the casualty was no longer defined as serious. Even then, if the casualty were still slightly injured, the benefit would be offset by the residual slight casualty cost.

Fatally injured casualties, in the IHRA accident dataset, normally suffered multiple injuries. For these casualties it was not possible to determine, from the data available, which of the multiple injuries had been the fatal ones. Indeed, since all injuries reduce the well being of the casualty, in one sense they all contribute to their death. For the purpose of the calculation, however, the assumption was made that if the worst injury or injuries of each fatally injured casualty was due to the car contact, then that fatality would be taken as having been caused by the car and would potentially be 'saved' by the IHRA procedures. 'Worst' injuries were taken as those where the AIS severity was the maximum for that casualty (e.g. if a casualty had injuries AIS 4, 4, 3, 3, 3, 2, 1 & 1 then the two AIS 4 injuries would be the 'worst' injuries). For a few of these cases counted as 'saved', in reality, it would be necessary also to prevent one or more less serious injuries caused by the ground to 'save' the fatality. This would result in a small overestimate of fatalities counted as 'saved'. However, in some cases fatalities counted as 'not saved', suffered two or more 'worst' injuries caused by a combination of car and ground. Then preventing only those injuries caused by the car might, in reality, have been sufficient to 'save' a fatality. This would result in a small underestimate of fatalities counted as 'saved'. Therefore, on balance, the method used to calculate fatalities 'saved' is considered to be reasonable.

For seriously injured casualties it was assumed that the serious casualty could be potentially 'saved' if all the AIS 2 to 5 injuries were caused by car contact. Casualties where there were both car contact and ground contact injuries in the AIS 2-5 range were counted as being potentially 20 percent 'saved', to reflect that there was some benefit in reducing the number of serious injuries.

The proportion of injuries caused by the car is higher at increased impact speeds. The data were therefore analysed for the three impact speed ranges of 0-30, 0-40 and 0-50 km/h.

There were a number of casualties where one of the injuries of interest had an injury source recorded of non-contact injury, or where it was not known if the car or the ground caused the injury. These cases were therefore discarded. The proportions for Car, Ground and Both were obtained as a proportion of the total of these three known categories. The proportions of casualties caused by car contact are shown in Table 7.2. This includes the 20 percent allowance for serious casualties in the 'both car and ground' category.

Table 7.2 Proportions (percent) of all fatal and serious casualties hit by car fronts that were injured at that severity by car contact, by impact speed range

Speed range (km/h)	Fatal (%)	Serious (%)
0-30	80	67
0-40	87	71
0-50	92	73

<u>**Proportions injured by the test area of the car**</u>: As the IHRA test procedures are intended to cover all parts of the car likely to hit the pedestrian in a frontal impact, this proportion is taken to be unity. However, if it should ever be decided to restrict the tested areas of cars then this assumption will no longer hold. It would then be necessary to include in the calculation chain the proportions who where injured by the test area, out of those injured by the car. This stage and the previous car or ground stage could be combined, as they involve a similar analysis procedure.

<u>**Proportions of pedestrians that could be 'saved' and reductions in casualties**</u>: The chain calculation of Figure 7.1 can now be applied to the two injury severity levels, at each of the three speed ranges being considered, to obtain the proportions shown in Table 7.3.

Table 7.3 Proportions (percent) of existing casualties injured by all vehicle types that could potentially be 'saved' by cars passing IHRA test methods, by 'uninjured up to the equivalent car speed' method

Speed range (km/h)	Fatal (%)	Serious (%)
0-30	5	17
0-40	14	28
0-50	26	35

However, while considerable reductions in casualties are possible, it is unlikely that the injury reductions for pedestrians currently fatally injured would be such that they would be 'uninjured' or 'slightly injured'. The most likely result is that they would be reduced to 'seriously injured'. The ratio of fatally injured to seriously injured pedestrians was obtained from the national statistics for Great Britain. This is 1 : 10, so for each ten percent reduction in fatalities the estimate for seriously injured casualties 'saved' needs to be reduced by one percent to allow for fatally injured casualties 'becoming' seriously injured casualties. This gives the final estimate of the reduction in casualty numbers, by this method, shown in Table 7.4. These percentages are of all pedestrians currently injured by all vehicle types.

Table 7.4 Potential reductions in pedestrian fatal and serious casualties due to cars passing IHRA test methods, as a percentage of pedestrians injured by all vehicle types, by 'uninjured up to the equivalent car speed' method

Speed range (km/h)	Fatal (%)	Serious (%)
0-30	5	17
0-40	14	27
0-50	26	33

In a similar manner, most of the seriously injured casualties 'saved' would still be slightly injured.

Estimating proportions that could be 'saved', by using the 'speed-shift' method

Davies and Clemo (1997) used a different method to determine the effect of equivalent car impact speed on the proportion of casualties that could be 'saved'. Otherwise, the calculation method is similar to that shown in Figure 7.1. This 'speed-shift' factor will apply only to casualties injured by the front of the car, not to those hit by the front of the car but injured by the ground.

For this study, a similar calculation has been performed, for each of the three impact speed ranges. However, in the description and Tables 7.5, 7.6 and 7.7 below the calculation is described and shown in detail only for an equivalent car impact speed of 40 km/h, to illustrate the method. All other factors are the same as those used in the previous section.

The concept is that there is an equivalent car impact speed at which most current cars would pass the test procedures. Davies and Clemo took for this purpose an impact speed of 25 km/h (for the EEVC test procedures). This same speed has been used in this current study, for IHRA test procedures. Test procedures with an equivalent car impact speed of 40 km/h would therefore lead to an improvement of 15 km/h in the 'safe' speed. (Corresponding improvements in 'safe' speeds are 5 km/h for an equivalent car impact speed of 30 km/h, and 25 km/h for 50 km/h.)

For the current car fleet there will be distributions of casualty injury risk varying with impact

Table 7.5 Estimation of 'speed-shift' factors, for test procedures with an equivalent car impact speed of 40 km/h

Speed band (km/h)	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120	121-130	131-140	141-150	Total
(A) Number of casualties from IHRA accident dataset																
Slight	141	192	148	82	38	9	2	0	0	0	0	0	0	0	0	612
Serious	48	126	149	172	111	59	23	7	4	3	1	0	0	0	0	703
Total	189	325	303	277	176	93	45	18	10	9	2	3	3	1	1	1455
(C) Predicted probability of injury at severity & within impact speed band																(B)
Slight	0.1701	0.2316	0.1785	0.0989	0.0458	0.0109	0.0024	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7382
Serious	0.0163	0.0427	0.0504	0.0582	0.0376	0.0200	0.0078	0.0024	0.0014	0.0010	0.0003	0.0000	0.0000	0.0000	0.0000	0.2380
Fatal	0.0000	0.0012	0.0010	0.0039	0.0046	0.0043	0.0034	0.0019	0.0010	0.0010	0.0002	0.0005	0.0005	0.0002	0.0002	0.0238
Total (D)	0.1863	0.2754	0.2300	0.1611	0.0880	0.0351	0.0136	0.0042	0.0024	0.0020	0.0005	0.0005	0.0005	0.0002	0.0002	1.0000
(E) Severity probabilities within each impact speed band																
Slight	0.9128	0.8408	0.7762	0.6141	0.5208	0.3094	0.1773	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
Serious	0.0872	0.1549	0.2194	0.3616	0.4270	0.5693	0.5724	0.5586	0.5701	0.4986	0.6654	0.0000	0.0000	0.0000	0.0000	
Fatal	0.0000	0.0043	0.0044	0.0243	0.0522	0.1213	0.2503	0.4414	0.4299	0.5014	0.3346	1.0000	1.0000	1.0000	1.0000	
Total	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
(F) Severity probabilities within each impact speed band, shifted by 15 km/h																
Slight	0	0.4564	0.8768	0.8085	0.6952	0.5674	0.4151	0.2434	0.0887	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
Serious	0	0.0436	0.1211	0.1871	0.2905	0.3943	0.4982	0.5709	0.5655	0.5643	0.5343	0.5820	0.3327	0.0000	0.0000	
Fatal	0	0.0000	0.0022	0.0044	0.0144	0.0383	0.0868	0.1858	0.3458	0.4357	0.4657	0.4180	0.6673	1.0000	1.0000	
Total	0	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	
(G) Predicted probability of injury at severity & within impact speed band, shifted by 15 km/h																(H)
Slight	0	0.1257	0.2016	0.1302	0.0612	0.0199	0.0056	0.0010	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5455
Serious	0	0.0120	0.0278	0.0301	0.0256	0.0138	0.0068	0.0024	0.0013	0.0011	0.0003	0.0003	0.0002	0.0000	0.0000	0.1218
Fatal	0	0.0000	0.0005	0.0007	0.0013	0.0013	0.0012	0.0008	0.0008	0.0009	0.0002	0.0002	0.0003	0.0002	0.0002	0.0086
Total	0	0.1377	0.2300	0.1611	0.0880	0.0351	0.0136	0.0042	0.0024	0.0020	0.0005	0.0005	0.0005	0.0002	0.0002	0.6760

speed. At the lowest speeds, most casualties will be slightly injured. At the highest speeds the risk of fatality will be virtually 100 percent. The next assumption is that the effect of test procedures with an equivalent car speed of 40 km/h will be to move this whole risk distribution up by 15 km/h.

The procedure here is first to obtain from the IHRA accident dataset the number of casualties by severity and impact speed bands. These data are shown in section (A) of Table 7.5.

There is probably some severity bias in the IHRA accident dataset, though it is less biased than the sample used by Davies and Clemo. The current study uses national statistics from Great Britain to adjust the severity proportions, so that the three severities are in the correct proportion. As no estimates are being made of absolute casualty numbers the adjustment is being made using the ratios of casualties at the different impact speeds. These are for pedestrians hit by the fronts of cars. These appear in Table 7.5 at (B), part of the total column. It should be noted that no account is being taken of unreported casualties. Were these allowed for, the proportions of less severely injured casualties would increase.

Data (A) and (B) are then used to predict the probability of injury for each severity and impact speed band, shown at (C) in Table 7.5. For example, the predicted probability in the 1-10 km/h speed band in the 'Slight' column of (C) is given as 0.1701; this has been calculated by taking the corresponding 'Slight' value from (A) of 141 and dividing it by 612 ((A) slight total) and multiplying the result by 0.7382 (the proportion of injuries in GB that were 'slight' (in B)). The total row in that section (D) shows the probability of being impacted at that impact speed range. Note that these probabilities are different to those that would be obtained from the raw IHRA accident dataset in (A), because of the adjustment using national statistics.

From (C), the probability of being injured at each severity has been obtained for each impact speed band, see section (E) of Table 7.5. These probabilities in (E) are then shifted by 15 km/h, see section (F) of Table 7.5. Davies and Clemo made the assumption that those hit at speeds up to 15 km/h would no longer be injured by the car, and that assumption is repeated here. Because the probability distribution is shifted by one and a half speed bands, the new probabilities in (F) have been obtained by averaging the two appropriate bands in (E).

The probability of casualties, currently injured by car fronts, being 'injured' by 'safe' cars can now be obtained for each severity, by using the probability of being impacted at each impact speed band (D) and the probability of injury at each severity (F). These probabilities are shown at (G).

These probabilities (G) can now be summed over all impact speed bands to obtain the probability of casualties currently injured by car fronts being 'injured' for each severity, see column (H) of Table 7.5. These probabilities (H) can then be compared with the original probabilities at (B), see Table 7.6. Note that the 'Safe' cars column no longer adds up to unity; the remainder are assumed to be uninjured. The Change column shows the proportionate changes in frequency for casualties of each severity. These are, when expressed as positive numbers, the proportions of casualties currently injured by car fronts, at impact speeds at which they could be 'protected' by 'safe' cars meeting the requirements of the test methods.

Table 7.6 Severity distribution for casualties injured by the fronts of current cars and for 'safe' cars, and percentage change, estimated using 'speed-shift' method, for test procedures at an equivalent car speed of 40 km/h

Severity	Current cars	'Safe' cars	Change (%)
Slight	0.7382	0.5455	-26
Serious	0.2380	0.1218	-49
Fatal	0.0238	0.0086	-64
All Severities	1	0.6760	-32

Hence the percentages of all pedestrians currently injured, by all vehicle types, that could be 'saved' can be calculated in a similar way to Figure 7.1. The 'car not ground' proportions for 40 km/h are used, as these are the most appropriate, even though the impact speeds for casualties potentially 'saved' no longer exactly corresponds to 0-40 km/h. The estimates are 35 percent for fatalities and 19 percent for seriously injured casualties, see Table 7.7.

Table 7.7 Calculation of potential reductions in pedestrian fatal and serious casualties due to cars passing IHRA test methods, as a percentage of pedestrians injured by all vehicle types, using the 'speed-shift' method, for an equivalent car impact speed of 40 km/h

Factor	This stage (%)		Cumulative (%)	
	Fatal	Serious	Fatal	Serious
Of pedestrian casualties hit by any vehicle, - those hit by cars	74	85	74	85
Of those pedestrian casualties, - those hit by car fronts	85	66	63	56
Of those pedestrian casualties, - those hit at survivable speeds ('speed-shift' method)	64	49	40	27
Of those pedestrian casualties, - those with injuries due to car	87	71	35	19

In a similar manner, estimates were obtained for equivalent car impact speeds of 30 and 50 km/h. The estimates, for all three equivalent car impact speeds considered, are shown in Table 7.8.

7.3 Discussion

Table 7.8 Potential reductions in pedestrian fatal and serious casualties due to cars passing IHRA test methods, as a percentage of pedestrians injured by all vehicle types, estimated by 'speed-shift' method

Equivalent car impact speed (km/h)	Speed shift due to implementing IHRA (km/h)	Potential casualty reduction (%)	
		Fatal	Serious
30	5	13	7
40	15	35	19
50	25	48	29

It should be noted that the benefits in casualties that could be 'saved' shown in Tables 7.4 and 7.8 are proportions of all pedestrians injured by all vehicle types. They are expressed in this way because the numbers of all pedestrian casualties are more easily available from national and international statistics, and can then be factored with the proportions given here to obtain estimates of casualty numbers that could be 'saved'. However, for some purposes it may be more appropriate to have estimates of the benefits as proportion of the casualties currently injured by the vehicle types that will be made safer. These can be obtained by removing the proportion hit by cars term from the calculation.

It can be seen in Tables 7.4 and 7.8 that the benefits increase greatly if the test procedures were applied at higher equivalent car impact speeds. However, achieving safety at higher speeds would be more difficult and more costly.

As explained in the method, the assumption was made that the IHRA test methods would cover all parts of the car that hit pedestrians in frontal impacts. It should be noted that these estimates therefore relate to the longer-term IHRA objective, not to a situation where only the high priority test methods have been implemented. Even in the long-term, there will inevitably be some injuries outside the scope of the test methods, for instance those caused when the car rides over the pedestrian. However, given the other uncertainties in these estimates, the assumption made is a reasonable approximation.

The analysis method required that a fatality be considered 'saved' only if all injuries deemed to have caused the fatality were from contact with the car and therefore assumed to be covered by the test procedures. In a similar way a serious casualty was only considered 'saved' if all serious injuries were car contacts, though a 20 percent allowance was made for 'saving' some of the serious injuries. It follows that if benefits were calculated for a limited set of test procedures, covering only parts of the likely contact area, the estimates obtained would be reduced. There would then be no benefit if one of the fatal injuries was caused by a part of the car not covered by the test procedures, and relatively little benefit if one of the serious injuries of a serious casualty were caused by a part of the car not covered by the test procedures. Reducing the tested area of cars might therefore reduce the benefits disproportionately to the reduction in the tested area.

The 'speed-shift' calculation is sensitive to the 'safe' speed chosen. This study used the same 25 km/h 'safe' speed as in the Davies and Clemo (1997) study. If for instance a 'safe' speed of 20 km/h were chosen, a speed shift of 20 km/h would then be required for a 40 km/h equivalent car impact speed.

The 'speed-shift' calculation predicted a saving of slight casualties, see Table 7.6, though this was not carried through to the final estimates for this method in Table 7.8. This saving arises from the assumption originally made by Davies and Clemo, and repeated in this study, that those hit at low speeds would effectively fall out of the impact speed and severity injury distribution when the speed shift was applied. However, a 'safe' car, designed with the stiffness characteristic selected to pass the test procedures, will not necessarily protect against slight car-contact injuries such as contusions (bruises). Also, these low impact speed casualties will include a higher proportion of ground contact injuries. Therefore, much of the reduction in slightly injured casualties implied in Table 7.6 will not occur in practice. The numbers of slightly injured casualties may even increase, as 'saved' seriously injured casualties are more likely to become slightly injured than uninjured.

The estimates by the two methods differ markedly, particularly in their relative benefits for the two severities, demonstrating that estimates of this type are not precise. The 'uninjured up to the equivalent car speed' method will tend to under-estimate the potential for saving lives. In reality, more of the stronger pedestrian fatalities will be saved above the test speed, than those weaker pedestrians who will not be saved at or below the test speed (acceptance criteria are typically set to protect all but the weakest 20 percent of the population). Also, most fatalities currently occur above the impact speeds considered here (see Figure 7.2). Similarly the 'uninjured up to the equivalent car speed' method is thought to produce a slight under-estimate of the serious casualties that could be saved by the test methods at an equivalent car impact speed of 30 km/h. The 'uninjured up to the equivalent car speed' method is thought on balance to produce good estimates of the serious casualties that could be saved by the test methods at equivalent car impact speeds of 40 and 50 km/h. This is because there is a slight under-estimate, due the low injury risk criteria being used, but this is balanced by a slight over-estimate, due to most serious injury accidents currently occurring at impacts speeds below 40 km/h (see Figure 7.2). The 'speed-shift' method tends to over-estimate the potential for saving lives at higher car speeds, as cars are likely to be optimised to just pass at the test speed, with little in-hand to provide protection at higher speeds. 'Safe' cars are likely to be more consistent in stiffness, as stiff areas are made safer. This will cause the impact speed distribution of serious casualties to become narrower, potentially increasing the proportions of casualties saved above the predictions of the 'speed-shift' method.

The predictions for casualties that could be saved can also be compared with those made by the previous studies that have already been referred to, see Table 7.9. The estimates from the 'uninjured up to the equivalent car speed' method are higher than those of Lawrence *et al* (1993), being about double for fatalities. For fatalities the largest contribution to the difference is the much higher proportion of fatalities below 40 km/h in the IHRA accident dataset, compared with the German data used by Lawrence *et al*. Covering all contact areas on cars also contributes to the higher estimate for the IHRA test procedures. For serious casualties the difference is mainly due both to a higher proportion of car not ground casualties in the IHRA accident dataset and again to the coverage of all contact areas on cars. The 'speed-shift' method estimates for the IHRA test

Table 7.9 Comparisons of current estimates with previous estimates, of potential reductions in pedestrian casualties for the EEVC test proposals, for a 40 km/h equivalent car impact speed

Severity	‘Uninjured up to the equivalent car speed’ method (%)		‘Speed-shift’ method (%)	
	IHRA test methods (this study)	EEVC test methods (Lawrence *et al*)	IHRA test methods (this study)	EEVC test methods (Davies & Clemo) ‡
Fatal	14	7	35	30
Serious	27	21	19	17

‡ Davies and Clemo’s ‘maximum estimate’, which uses some estimates from Lawrence *et al*.

procedures are much closer to the estimates for the EEVC test procedures, made by Davies and Clemo. Using the IHRA accident dataset impact speed distribution rather than the impact speed distribution used by Davies and Clemo reduced the estimates for the proportion of casualties struck at survivable speeds. However, excluding the ‘hit by the test area’ factor and the higher proportion of serious car not ground casualties more than compensated for this.

Casualty reductions could largely be achieved in Europe and Japan by applying test methods only to cars (i.e. not vans or pickups). However, to achieve equivalent reductions in the USA, it would be necessary to include within the scope of the test methods vehicle types such as pick-ups that are widely used as passenger cars, i.e. that are used for private passenger transport (the IHRA test methods are intended to be suitable for testing the smaller models of pick-ups).

Conclusions

1. Estimates have been made of the benefits that could be obtained by introducing the test methods that are under development by the IHRA Pedestrian Safety Working Group, as proportions that could be saved of all pedestrian fatal and serious casualties.

2. The benefits were estimated using two different methods for obtaining the proportions of casualties who are currently injured by car fronts at impact speeds at which they could be protected, the ‘uninjured up to the equivalent car speed’ method and the ‘speed-shift’ method.

3. For an equivalent car impact speed of 40 km/h the two methods predict potential reductions in the number of pedestrian casualties of 14 percent and 35 percent for fatalities and 27 percent and 19 percent for seriously injured casualties. The differences between the two methods of estimating benefits indicate that such estimates cannot be made precisely.

4. The estimates were made for tests at equivalent car impact speeds of 30, 40 & 50 km/h; it is shown that the benefits are much larger if the test procedures are applied at higher speeds.

5. The benefits were calculated assuming full coverage of the parts of cars impacted in frontal impacts. However, had the benefits been calculated for a limited set of test procedures, covering only parts of the likely contact area, then the estimates obtained would have been reduced.

References

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Jacobs G, A Aeron-Thomas and A Astrop. Estimating global road fatalities. *TRL Report TRL445.* Crowthorne, UK: TRL Limited, 2000.

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Lawrence G J L, B J Hardy and R W Lowne. Costs and benefits of the EEVC pedestrian impact requirements. *Project Report 19*. Crowthorne, UK: TRL Limited, 1993.

Yoshida S, N Igarashi, A Takahashi and I Imaizumi. Development of a vehicle structure with protective features for pedestrians. *SAE paper 1999-01-0075, presented at the International Congress and Exposition, Detroit, USA, March 1999*. Warrendale, USA: Society of Automotive Engineers, 1999.

CHAPTER 7: IMPLICATIONS FOR REGULATIONS

(B) OTHER MEASURES

It is recognised that improvement of the level of pedestrian protection provided by the design of the front of the car is only one of many ways of reducing pedestrian casualties. Road and traffic engineering measures, such as reducing vehicle travelling speeds by lower speed limits, can also be expected to reduce the frequency of collisions with pedestrians and the severity of those collisions that do occur.

There are also other measures available within the scope of vehicle engineering. For instance, the ASV developed in Japan in 2000 has pedestrian accident avoidance features. It has a pedestrian detection warning system for night-time use. This system detects the pedestrian, on the road or crossing, at distances beyond the range of the vehicle front lights (about 30 - 80 m) when the vehicle is running at about 30-60 km/h. It sounds and displays to the driver a warning of the pedestrian's presence. It also has a blind-spot warning system, which detects the pedestrian when the vehicle starts forward or backward.

However, even with advances in road and traffic engineering, and other measures, there will still be a need to minimise the severity of injury sustained by a pedestrian struck by a car.

CHAPTER 8: ACHIEVEMENTS & RECOMMENDATIONS

8.1 Achievements

This project has run for four years since July 1997, when the first IHRA/PS experts meeting was held, until the ESV International Conference in June 2001. Nine experts meetings have been held so far. The know-how of experts has been fully used and research in new areas has been conducted.

Over this period, detailed information on pedestrian-involved traffic accidents in member countries and other relevant information from investigations conducted to date has been gathered and analyzed. Data for traffic accidents in member countries reveal that although the percentages of pedestrian-involved accidents vary with each country, the percentages are relatively high.

Since some member countries intend to introduce technical regulations like those in the EU (based on EEVC test methods), the IHRA/PS WG is conscious of the need to propose appropriate, harmonized test procedures as a basis for future harmonization of the regulations that will requiring additional protection compared with that proposed by EEVC. The work that has been done to develop the proposed EU regulation forms a useful basis for the development of internationally harmonised test procedures that:

(a) cover a larger area of front surface of the vehicle
(b) cover a larger range of vehicles
(c) cover higher impact speeds
(d) protect more areas of the pedestrian's body.

However, requiring additional pedestrian protection is a comparatively new field and so the available information is not yet completely adequate for the development of comprehensive and validated test procedures.

Pedestrian crash test dummies are not generally available at present, although a pedestrian dummy is being developed by the private sector. An inquiry was made to the IHRA/Bio WG, but they replied that dummies cannot be developed yet due to the time and cost required. It is also the opinion of the Pedestrian Experts WG that the kinematics of the vehicle/pedestrian collision may prove to be too difficult to reproduce in a valid and repeatable manner with a pedestrian crash test dummy. Accordingly, after careful consideration, it was decided to use subsystem test procedures which, at least at this stage, are more practical and repeatable. Interactions between the results of the subsystem tests will be studied using computer simulation of the collision events once a comparison of existing computer simulation programs has been completed.

Proposals for head impact subsystem test procedures for adults and children are nearly complete. These are top-priority issues. Proposals for test procedures for the adult leg are also being considered. Other areas of the human body will be researched in the future.

8.2 Continuation of IHRA/PS Activities

The aim of the IHRA/PS WG is to prepare test procedures for the child and adult head, and the adult leg, for presentation at the ESV Conference in 2003 and 2005, together with recommendations for research activities that will be needed to develop other test procedures for the further improvement of pedestrian protection.

In the field of pedestrian crash injury biomechanics there are still areas which must be investigated and their practical applications explored. We plan to first clarify the issues, necessities and research responsibilities through detailed investigations. The following issues will be studied.

(1) Comparative evaluation of the results of, and interactions between, subsystem test procedures and test procedures employing a computer simulation program based on the best such programs currently available.
(2) Regarding leg impacts on the pedestrian, we plan to confirm the injury mechanisms and tolerance of the leg to impact. This will be followed by evaluation of available and proposed impactors and development of test procedures based on the results.
(3) Clarification of the importance of injury mechanisms to areas other than the head or legs; also, R&D on impactors to confirm such injury mechanisms

This work will be greatly facilitated if member countries are prepared to cooperate and share the cost, conduct further studies, and assist in the development of essential test procedures.

CHAPTER 9: REFERENCES

(1) IHRA/Pedestrian Safety Experts Member List
See Appendix A.

(2) Past Meeting Schedule and Venues
See Appendix B.

(3) Global Pedestrian Accident Dataset
See Appendix C.

(4) Test Methods
Adult Head Test Method (Draft) See Appendix D.
Child Head Test Method (Draft) See Appendix E.

(5) Document List
See Appendix F.

(6) Technical Feasibility (OICA)
See Appendix G.

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Mr. Norbert Jaehn (ACEA), European Automobile Manufacturers Association

Mr. Akira Sasaki (JAMA), HONDA R&D Co., Ltd.

Appendix B: Past Meeting Schedule and Venues

1st Meeting:	July 15-16, 1997	Tokyo, Japan
2nd Meeting:	March 3-5, 1998	Washington, D.C., U.S.A.
3rd Meeting:	September 9-11, 1998	Brussels, Belgium
4th Meeting:	February 22-24, 1999	Adelaide, Australia
5th Meeting:	September 15-17, 1999	Tokyo, Japan
6th Meeting:	March 15-17, 2000	Washington, D.C., U.S.A.
7th Meeting:	September 25-28, 2000	Paris, France
8th Meeting:	February 5-8, 2001	Adelaide, Australia
9th Meeting:	May 8-10, 2001	Gotemba, Japan